TR 00RTO43-02

FREE FLIGHT RESEARCH ISSSUES AND LITERATURE SEARCH

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Prepared for:
NASA Ames Research Center
Moffett Field, CA 94035

Under NASA Contract NAS2-98005
September, 2000

Submitted by:

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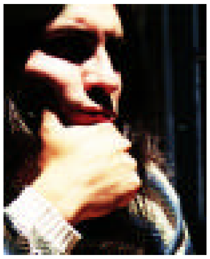
Acknowledgments

This research was funded by NASA Ames Research Center under contract NAS2-98005 for the Advanced Air Transportation Technologies (AATT) program. The authors appreciate the program support and active research participation of Dr. Richard Mogford at NASA Ames Research Center, Moffett Field, CA. The assistance of Dr. Tony Andre of Interface Analysis Associates is also appreciated.

ABOUT THE AUTHOR



Jimmy Krozel, Senior Research Engineer (Ph.D., Aeronautical and Astronautical Engineering, Purdue University, 1992)**.** Since joining Seagull Technology in Aug., 1995, Dr. Krozel has worked on aircraft conflict detection and resolution for Free Flight, decentralized control for traffic separation, the database management of aircraft, terrain, and navigation aid data, collaborative decision making, aircraft terminal area routing around heavy weather, and intent inference for aircraft. His research interests are in the areas of advanced visualization systems, air traffic control, air traffic management, Free Flight, route planning, autonomous vehicles, and intelligent path prediction. Dr. Krozel performed his M.S. thesis research under a fellowship at the NASA Ames Research Center, and performed his Ph.D. thesis as a Hughes Doctoral Fellow at the Hughes Research Laboratory. Dr. Krozel is a member of the American Institute of Aeronautics and Astronautics, American Association for Artificial Intelligence, Tau Beta Pi, Sigma Xi, and Sigma Gamma Rho. Dr. Krozel has a total of 20 technical publications, has received two “Best Paper” Awards at AIAA conferences, and is on the editorial board of *Applied Intelligence*, Kluwer Academic Publishers.

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ABSTRACT

The Distributed Air/Ground Traffic Management (DAG-TM) allows for distributed decision-making for traffic separation and traffic flow management. In contrast to the current traffic management system which is a centralized, ground-based positive Air Traffic Control (ATC) system, DAG-TM allows for an advanced Free Flight Air Traffic Management (ATM) concept that is a decentralized control system utilizing a triad of agents: the Flight Deck (FD), Air Traffic Service Provider (ATSP), and Airline Operational Control (AOC). In this report, the process of how a comprehensive review of Free Flight research supporting the DAG-TM paradigm of air traffic operations is documented. In the literature survey, emphasis is given to empirical studies involving simulation-based experiments. In addition to identifying current findings, this investigation is aimed at identifying DAG-TM research needs that are not covered in the current literature.

List of Acronyms

AATT..............Advanced Air Transportation Technologies
ADS-B ....Automatic Dependent Surveillance – Broadcast
AILS...............Airborne Information for Lateral Spacing
ANOVA..........Analysis of Variance
AOC...............Airline Operational Control
ASAS..............Airborne Separation Assurance System
ATC................Air Traffic Control
ATM ....Air Traffic Management
ATSP..............Air Traffic Service Provider
CARS.............Controller Operational Acceptability Rating
CE...................Concept Element of DAG-TM
CDM..............Collaborative Decision Making
CD&R............Conflict Detection and Resolution
CDTI..............Cockpit Display of Traffic Information
CNS................Communication, Navigation, and Surveillance
CTAS..............Center-TRACON Automation System
CWIN.............Cockpit Weather Information
DAG-TM........Distributed Air Ground Traffic Management
DST................Decision Support Tool
FAA................Federal Aviation Administration
FD..................Flight Deck
FMC...............Flight Management Computer
IFR.................Instrument Flight Rules
IGS.................Intelligent Ground System
NAS................National Airspace System
NASA.............National Aeronautics and Space Administration
NRP................National Routing Program
RI....................Research Issue of Free Flight
RSME.............Rating Scale of Mental Effort
RTCA.............Radio Technical Commission for Aeronautics
STAR..............Standard Arrival Route
SUA................Special Use Airspace
TCAS..............Traffic Collision Alert System
TLX................NASA's Task Load Index
TFM...............Traffic Flow Management
URET.............User Request Evaluation Tool
WWW............World Wide Web

1.0 INVESTIGATION

This report presents a survey of Free Flight research issues and concepts. The literature survey is being conducted to support NASA's Advanced Air Transportation Technologies (AATT) project, and the development and validation of Distributed Air-Ground Traffic Management (DAG-TM) concepts of operation. In the literature survey, emphasis is given to empirical studies involving simulation-based experiments including the Flight Deck (FD), Air Traffic Service Providers (ATSP), Airline Operational Control (AOC), Decision Support Tools (DSTs), Air Traffic Management (ATM), roles, responsibilities, and procedures. In addition to identifying current findings, this investigation is aimed at identifying DAT-TM research needs that are not covered in the current literature.

In this chapter, we define the Free Flight concepts and issues being addressed, key words associated with these concepts and issues, the approach to the literature survey, initial literature survey findings, and the report organization.

1.1 Free Flight Concepts and Issues

Free Flight concepts and issues are discussed based on the following sources of information[1]:

- RTCA Task Force 3 Free Flight Report [RTCA95][2];
- Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM) [DAG99];
- FAA Free Flight home page (http://www.faa.gov/freeflight/), recorded in Appendix A;
- National Airspace System Architecture Version 4.0 [FAA99]; and
- Comments from Stakeholders based on an e-mail survey.

1.1.1 Free Flight

Through the work of the RTCA in 1994 and 1995 [RTCA95], Free Flight has been defined by a group of over 200 professionals from the aviation industry. Free Flight has been defined in [RTCA95] and later quoted in [DAG99] and [FAA99] as the following:

> *"... a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorized flight through Special Use Airspace (SUA), and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity which removes restrictions represents a move toward free flight."*

On the FAA's Free Flight home page (Appendix A), additional information is provided:

> *"Free Flight is an innovative concept designed to enhance the safety and efficiency of the National Airspace System (NAS). The concept moves the NAS from a centralized command-and-control system between pilots and air traffic controllers to a distributed system that allows pilots, whenever practical, to choose their own route and file a flight plan that follows the most efficient and economical route. Free Flight calls for limiting pilot flexibility in certain situations, such as, to ensure separation at high-traffic airports and in congested airspace, to prevent unauthorized entry into special use airspace, and for any safety reason. In essence, any activity that removes restrictions represents a move toward Free Flight."*

From these two definitions, we identify 'key words' that will help to formulate a survey of the literature:

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[1] *Italics* is used to identify sentences that are written as presented by the original authors.

[2] References are cited using [ ] notation with author initials and publication date; see Chapter 3.

Key Words: Free Flight, Safety, Efficiency, Capacity, User Preferences, Separation Assurance, Conflict Detection and Resolution, Distributed/Decentralized Control System, Workload

Next, separation assurance is described in the Free Flight home page (Appendix A) as follows:

> *"Central to the Free Flight concept is the principle of maintaining safe airborne separation. This principle is based on two airspace zones, protected and alert, the sizes of which are based on the aircraft's speed, performance characteristics, and communications, navigation, and surveillance equipment. The protected zone, the one closest to the aircraft, can never meet the protected zone of another aircraft. The alert zone extends well beyond the protected zone, and aircraft can maneuver freely until alert zones touch. If alert zones do touch, a controller may provide one or both pilots with course corrections or restrictions to ensure separation. Eventually, most commands will be sent via data link, an integrated network of air, ground, and airborne communications systems. Additionally, onboard computers and Global Positioning System satellites will allow pilots, with the concurrence of controllers, to use airborne traffic displays to choose solutions."*

Key Words: Separation Assurance, Conflict Detection and Resolution, Alert Zones, Datalink, Collaborative Decision Making, CDTI

Figure 1 illustrates the concept of the Protected Airspace Zone and Alert Zone for Free Flight.

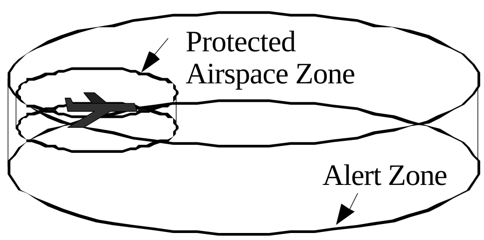

Figure 1. The Protected Airspace Zone and Alert Zone for Free Flight.

1.1.2 Distributed Air-Ground Traffic Management (DAG-TM)

The Distributed Air-Ground Traffic Management (DAG-TM) concept allows for distributed decision-making for traffic separation and traffic flow management. Within this DAG-TM paradigm, user preferred trajectories can be planned to allow airlines to optimize their operations. Self-optimization is the objective rather than NAS system optimization. Thus, with no requirement for a centralized, positive ATC system, a decentralized/distributed control system becomes the focus of attention. DAG-TM allows for an advanced Free Flight ATM concept that utilizes a triad of agents, as shown in Figure 2.

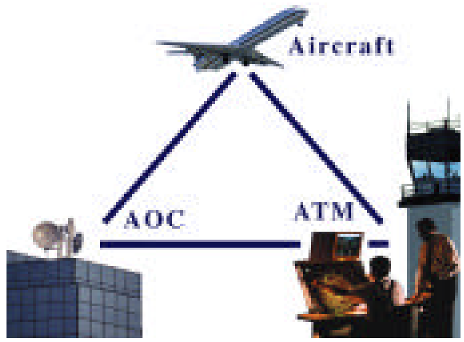

Figure 2. DAG-TM is applicable to tasks performed by a triad formed by AOC, FD, and ATM.

The vision statement for DAG-TM is as follows [DAG99]:

> *"Distributed Air/Ground Traffic Management is a National Airspace System concept in which flight deck (FD) crews, air traffic service providers (ATSP) and aeronautical operational control (AOC) facilities use distributed decision-making to enable user preferences and increase system capacity, while meeting air traffic management requirements. DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS) / Air Traffic Management (ATM) technologies."*

As shown in Table 1,the DAG-TM paradigm has 15 Concept Elements (CEs).

Table 1. The DAG-TM Concept Elements ([DAG99],[GBB00]).

CE	Flight Phase	Title
0	Gate-to-Gate:	Information Access/Exchange for Enhanced Decision Support
1	Pre-Flight Planning:	NAS-Constraint Considerations for Schedule/Flight Optimization
2	Surface Departure:	Intelligent Routing for Efficient Pushback Times and Taxi
3	Terminal Departure:	Free Maneuvering for User-Preferred Departures
4	Terminal Departure:	Trajectory Negotiation for User-Preferred Departures
5	En route: *(Departure, Cruise, Arrival)*	Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
6	En route: *(Departure, Cruise, Arrival)*	Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
7	En route: *(Departure, Cruise, Arrival)*	Collaboration for Mitigating Local TFM Constraints due to Weather, SUA and Complexity
8	En route / Terminal Arrival:	Collaboration for User-Preferred Arrival Metering
9	Terminal Arrival:	Free Maneuvering for Weather Avoidance
10	Terminal Arrival:	Trajectory Negotiation for Weather Avoidance
11	Terminal Arrival:	Self Spacing for Merging and In-Trail Separation
12	Terminal Arrival:	Trajectory Exchange for Merging and In-Trail Separation
13	Terminal Approach:	Airborne CD&R for Closely Spaced Approaches
14	Surface Arrival:	Intelligent Routing for Efficient Active-Runway Crossings and Taxi

Each CE is defined in general as follows [DAG99]:

CE 0: “ *Provide capabilities to all stakeholders (FD, AOC, ATSP) for convenient access/exchange of timely and accurate information.”*

Key Words: Datalink, NAS Information Management

CE 1: “ *Using information on current and predicted NAS constraints, users collaborate with the ATSP during pre-flight planning to determine “optimal” (user-preferred) schedules and trajectory plans that satisfy current and predicted NAS constraints.”*

Key Words: Optimal 4D Flight Planning, Re-Planning, User Preferences

CE 2: “ *ATSP uses an Intelligent Ground System (IGS) to determine pushback time, based on an estimated departure time transmitted (via datalink) by the user/ramp.”*

Key Words: Ground Delays, Surface Traffic Management

CE 3: “ *Appropriately equipped aircraft are given authority to select departure path and climb profile in real time, along with the responsibility to ensure separation from local traffic.”*

Key Words: Climb Profile, Departure Efficiency, Conflict Detection and Resolution, Self-Separation, CDTI

CE 4: “ *User and ATSP collaboratively plan a user-preferred departure trajectory.”*

Key Words: Collaborative Departure Scheduling, Collaborative Routing, Collaborative Decision Making, User Preferences

CE 5: “ *Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local traffic flow management constraints.”*

Key Words: Conflict Detection and Resolution, User-Preferred Trajectories, Trajectory Negotiation, TFM Conformance, Decision Support Tools, Mixed Equipage, Workload

CE 6: “ *Reduce unnecessary and/or excessive ATSP-issued route deviations for traffic separation by enhancing ATSP trajectory prediction capability through user-supplied data on key flight parameters. Facilitate trajectory change requests for en route aircraft by providing the user (FD and/or AOC) the capability to formulate a conflict-free user-preferred trajectory that conforms to any active local-TFM constraints.”*

Key Words: Trajectory Prediction, User-Preferred Trajectories, TFM Conformance, Conflict Detection and Resolution, Trajectory Negotiation, Datalink, Workload

CE 7: “ *A system-wide collaboration between ATSP and multiple users (FDs and/or AOCs), with the objective of eliminating or mitigating the impact of predicted NAS operational constraints due to bad weather, SUA and complexity.”*

Key Words: Collaborative Decision Making, Datalink, Airspace Complexity, Dynamic Density, TFM Conformance, Dynamic Resectorization, Decision Support Tools

CE 8: “ *Users influence arrival handling by submitting preferences for arrival time, meter-fix and runway to the ATSP well in advance of the arrival-planning freeze horizon.”*

Key Words: Arrival Metering/Spacing, Decision Support Tools, Required Time of Arrival, Collaborative Arrival Planning, Mixed Equippage

CE 9: “ *Properly equipped aircraft are given authority to maneuver as necessary to avoid weather cells, or to follow such aircraft using self-spacing procedures.”*

Key Words: Weather Avoidance, Decision Support Tools, Mixed Equipage, Workload

CE 10: “ *User and ATSP collaboratively plan a user-preferred trajectory around bad weather cells.”*

Key Words: Collaborative Decision Making, Collaborative Arrival Planning, Weather Avoidance, Decision Support Tools, User-Preferred Trajectories

CE 11: “ *Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.”*

Key Words: In-Trail Spacing, Decision Support Tools, CDTI, Conflict Detection and Resolution, Mixed Equipage, Workload

CE 12: “ *Trajectory exchange between FD and ATSP to improve the accuracy of FD-based and ATSP-based DSTs for accurate merging and in-trail separation with minimal buffers.”*

Key Words: In-Trail Spacing, Decision Support Tools, Datalink, Trajectory Prediction, Conflict Detection and Resolution, Workload

CE 13: “ *Appropriately equipped aircraft may conduct closely-spaced independent approaches by utilizing surveillance data, on-board avionics and new air-ground procedures to ensure safe separation.”*

Key Words: Closely-Space Approaches, Decision Support Tools, CDTI, Mixed Equipage, Conflict Detection and Resolution, Workload

CE 14: “ *ATSP uses an Intelligent Ground System (IGS) and datalink technology to coordinate aircraft for efficient active runway crossing.”*

Key Words: Surface Traffic Management, Runway Crossings, Datalink, Workload

1.1.3 Researchers and Stakeholders

In order to identify important research issues for Free Flight, an e-mail survey was conducted (Appendix B contains the survey and results) to ask researchers, scientists, engineers, professors, pilots, AOC dispatchers, and air traffic controllers the following question: *What do you think are the three most important research issues that must be addressed for Free Flight to be implemented by 2015?*. The year 2015 was chosen since it is referred to in [DAG99] as a target date of operation. Next, some responses to this question are highlighted. Issues included:

- *"To achieve the functional/performance goals of free-flight, the system must be affordability, reliable, and safe."*
- *"Human-computer interface issues; In the end, if we don't develop well designed interfaces, everything fails."*
- *"roles and responsibilities of flight crew vs ATC service provider"*
- *"Rigorous operational concept exploration and validation"*
- *"Minimize cost to airlines"*
- *"Transition from today to free Flight"*
- *"obtaining controller acceptance of system changes through appropriate development methods"*
- *"Controller and pilot acceptance of new ways of doing functions they do today."*
- *"The interrelationships between strategic flow, tactical flow and separation assurance."*
- *"information collection and coordination"*
- *"Congestion management and predictability of airspace constraints"*
- *"Operation of Free Flight within an airspace environment where some users are equipped with modern technology (ADS-B, data-link, etc.) and other users are not equipped."*

From the e-mail survey, the following Key Words were attained (number of occurrences is listed in parenthesis):

Key Words:	Roles, Procedures, and Responsibilities	(15)
	Safety or Airborne Separation Assurance	(13)
	Traffic Prediction and Airspace Management	(11)
	Information Distribution	(9)
	Equipment and DST Reliability	(9)
	Human Factors Issues	(8)
	Collaboration	(7)
	Operational Concept Validation	(6)
	Economic Issues	(5)
	Accommodation of Mixed Equipage	(4)
	Evolution Complexities	(4)
	Capacity and Efficiency	(3)
	Weather data collection and Distribution	(3)
	User and ATSP Acceptance	(3)
	NAS Performance Evaluation and Feedback	(2)
	FAA Political and Organizational Reform	(2)
	Realizing User Preferences	(1)
	Gaming and Equality	(1)

1.1.4 Free Flight Research Issues Guiding the Literature Survey

The above discussion of Free Flight concepts and issues (and associated key words) are next used to identify the issues that will be used to guide the literature survey. Research issues are stated as questions, since an emphasis is given in this literature survey to empirical studies and such studies usually investigate well formulated questions. There is no particular order in the following list of research issues:

RI 1. What will be the role and responsibility of the pilot in Free Flight?
Key Words: Free Flight, Roles and Responsibilities, Human Factors, Pilot

RI 2. What will be the role and responsibility of the air traffic controller or air traffic service provider in Free Flight?
Key Words: Free Flight, Roles and Responsibilities, Human Factors, ATC Controller

RI 3. What will be the role and responsibility of the AOC dispatcher in Free Flight?
Key Words: Free Flight, Roles and Responsibilities, Human Factors, AOC Dispatcher

RI 4. How can information distribution and collaborative decision making enable user preferences in Free Flight?
Key Words: Free Flight, Information, Collaborative Decision Making, User Preferences

RI 5. How will pilots and air traffic service providers share the responsibility for separation assurance in a Free Flight environment?
Key Words: Free Flight, CD&R, Separation Assurance, Roles and Responsibilities

RI 6. What new CDTIs and other cockpit DSTs are needed for pilots to effectively participate in Free Flight?
Key Words: Free Flight, CDTI, Human Factors, Workload, Cockpit DSTs, Pilot

RI 7. What new DSTs will enable greater user preferences of the AOC dispatcher in Free Flight?
Key Words: Free Flight, DSTs, Workload, User Preferences, AOC dispatcher

RI 8. What new DSTs will enable air traffic service providers in Free Flight?
Key Words: Free Flight, DSTs, Workload, ATSP

RI 9. How will airspace be dynamically managed to control workload and safety in Free Flight?
Key Words: Free Flight, Dynamic Density, Airspace Complexity, Workload, Safety

RI 10. Do current DSTs that will be used in the initial Free Flight environment abide by human-centered-automation guidelines?
Key Words: Free Flight, DSTs, Human-Centered Automation, Human Factors

RI 11. What level of automation is required or desired in the design of new interfaces for pilots or controllers?
Key Words: Free Flight, Interfaces, Human-Centered Automation, Human Factors

RI 12. How will Datalink change the nature and efficiency of communication?
Key Words: Datalink, Communication.

1.2 Literature Survey Approach

In this section, we present the assumptions of the literature survey, the sources of material, the organizations targeted for material, and the literature search process.

1.2.1 Assumptions

The assumptions to the literature survey are:

- Time period of material considered will be from 1990 to date (unless important concepts or issues require reference to classical papers in the literature prior to 1990)
- Type of search material will not include World-Wide-Web (WWW) pages, video, or audio material (the only exception is the use of the FAA WWW page defining Free Flight)

- No books will be reviewed (except when certain chapters of books are directly applicable to the literature survey)
- Only literature published in English will be reviewed.

1.2.2 Sources of Material

The following sources of material will be used for the literature survey:

- Seagull Technology Technical Library
- Stanford Terman Engineering Library
- NASA Ames Technical Library
- ASAP (Center for Aerospace Information)
- NASA Technical Reports Server
- WWW pages (downloadable papers from NASA, FAA, and University programs)
- IEEE, ACM Digital Library, NTIS and DTIC databases

1.2.3 Organizations Targeted for Material

The following organizations will be targeted for material for the literature survey:

- NASA (Ames, Dryden, Glenn, and Langley Research Centers),
- FAA (Tech. Center, CAMI), MIT Lincoln Labs, MITRE CAASD,
- Eurocontrol (e.g., FREER program), DLR, NLR,
- Universities (e.g., Ohio State, Univ. of IL, MIT, Stanford, San Jose State, Univ. of MN, UC Berkeley, Princeton, Embry Riddle, and others),
- Industry supporting FD (e.g., Boeing, Smiths Industries, Rockwell-Collins, Honeywell),
- Industry supporting AOCs (e.g., SABRE, Metron, Dimensions International),
- Industry supporting ATC (e.g., NARI), and
- Industry supporting ATM automation (e.g., Raytheon, Lockheed-Martin, CSC, Rockwell).

1.2.4 Survey Process

Because there is a limited amount of time in this research effort to perform a literature survey, an "anytime algorithm", defined as follows, is used for the literature survey approach. Topics are covered evenly and surveyed incrementally through the project. Thus, at any time, the search process can stop and the results can be summarized.

The search will be driven by key words identified in the definition of Free Flight and the important research issues for Free Flight. Key words will include the major stakeholders, roles and responsibilities, processes, procedures, and organizations.

Documentation of the key word search will be performed by listing a partial citation of the search results (full citations are listed in Section 3.0 References), and identifying key words associated with the title and abstract information. The following format is used:

> [MGMK95] Mogford, Guttman, Morrow, and Kopardekar, *The Complexity Construct in Air Traffic Control: A Review and Synthesis of the Literature*
>
> *Key Words*: ATC, Sector Complexity, Traffic Complexity, Airspace Complexity, Workload, Survey Paper

All the papers found in the search will be ranked (H=High, M=Medium, L=Low) based on how well the paper addresses one or more of the important Free Flight research issues. At this stage the rating (H, M, or L) will be highly subjective because only the title and/or abstract will be known (unless fully read or reviewed in previous work). The criteria for ranking are as follows:

H=High	High relevance to Free Flight, DAG-TM, empirical results, human factors experiments
M=Medium	High relevance to Free Flight, DAG-TM, human factors; but no empirical results

L=Low	Relevance to Free Flight, DAG-TM; but no empirical results or limited human factors

A review of a paper includes reading it, writing a synopsis, and collecting the data needed for the analysis and comparison of papers. If the paper has been previously reviewed, then the reading and key word parts of this process may be eliminated. The review process is driven by the ranking (H, M, or L). The review will proceed with all H ranked papers first before proceeding to M or L ranked papers.

The synopsis will provide a brief description of the research effort. While similar to an abstract, it differs in that the synopsis will not only present what the research effort addressed, but it will also discuss how it relates to the important issues related to Free Flight.

The final step in the process is to analyze and compare the surveyed papers. The following information is identified:

- Primary result or contribution of the research,
- Relevance to one or more triad category ATM/AOC/FD,
- Relevance to one or more of the important research issues of Free Flight,
- Relevance to one or more DAG-TM CE #1 through CE #14,
- Approach: Theoretical, Observations based on operational data, Questionnaire, Fast-Time vs. Real-Time simulation, Human-in-the-loop simulation, Flight test, etc.,
- Major limitations or questionable assumptions of the research,
- Clarity and/or quality of the methods, assumptions, and approaches so that the experiment or study can be verified or duplicated by other researchers, and
- Research questions that are not currently addressed by the research.

Figure 3 illustrates the survey process.

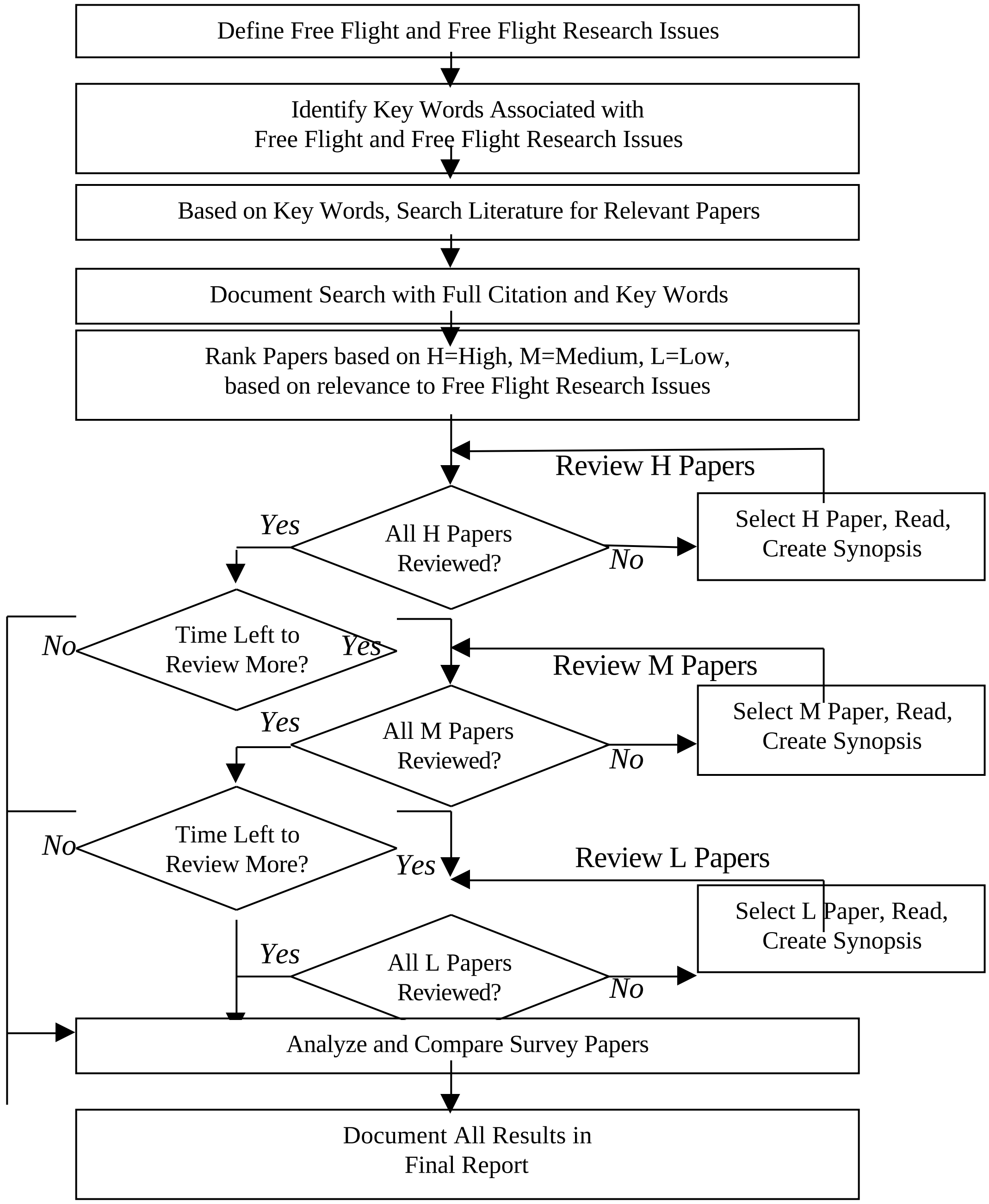

Figure 3. The survey process follows an anytime algorithm logic.

1.3 Literature Survey

In this section, we present the initial findings of our literature survey. These findings are based on our initial set of concept elements, research issues, and key words identified in this report. The literature is ranked according to the method described in Section 1.2.4.

1.3.1 Pre-Flight Planning: NAS-Constraint Considerations for Schedule/Flight Optimization

None

1.3.2 Surface Departure Intelligent Routing for Efficient Pushback Times and Taxi

[L] [GH00] Gilbo and Howard, "Collaborative Optimization of Airport Arrival and Departure Traffic Flow Management Strategies for CDM"
Key Words: Free Flight, CDM, User Preferences, Optimization, Departure Planning

[L] [AIC00] Anagnostakis, Idris, et al., "A Conceptual Design of a Departure Planner Decision Aid"
Key Words: ATM, Terminal Area, Ground Movement Planning, Departure Planning, Optimization

[M] [MHB98] Martin, Hudgell, and Bouge, "Improved Information Sharing: A Step Towards the Realisation of Collaborative Decision Making"
Key Words: Information Sharing, CDM, Airlines, AOC, Information Requirements

[M] [OSD98]Obradovich, Smith, et al, "Cooperative Problem-Solving Challenges for the Movement of Aircraft on the Ground"
Key Words: Cooperative Problem Solving, AOC, Surface Movement, Structured Interviews, Human Factors

1.3.3 Terminal Departure Free Maneuvering for User-Preferred Departures

[H] [BH99] Barhydt and Hansman, "Experimental Studies of Intent Information on Cockpit Traffic Displays"
Key Words: Free Flight, Pilot, CDTI, Intent, Experiment, Conflict Detection and Resolution

[L] [BS99]Bolender and Slater, "Cost Analysis of the Departure-En Route Merge Problem"
Key Words: Departure Airspace, Merging, Merge Strategies

[L] [Co99]Coppenbarger, "En Route Climb Trajectory Prediction Enhancement Using Airline Flight-Planning Information"
Key Words: Departure, Collaboration, CTAS, Trajectory Prediction, Pilot Intent

1.3.4 Terminal Departure Trajectory Negotiation for User-Preferred Departures

None

1.3.5 Free Maneuvering for User-Preferred Separation and Local TFM Conformance

[L] [AH97] Andrews and Hollister, "Impact of Intent-Based Maneuver Constraints on Alert Rates"
Key Words: Free Flight, Conflict Alert, CD&R, Intent

[M] [BJ98]Battiste and Johnson, "Development of a Cockpit Situation Display for Free-Flight"
Key Words: Free Flight, Separation Assurance, CDTI, en route, terminal area

[H] [BH99] Barhydt and Hansman, "Experimental Studies of Intent Information on Cockpit Traffic Displays"
Key Words: Free Flight, Pilot, CDTI, Intent, Experiment, Conflict Detection and Resolution

[L] [BLM00]Bilimoria, Lee, et al, "Comparison of Centralized and Decentralized Conflict Resolution Strategies for Multiple-Aircraft Problems"
Key Words: Free Flight, CD&R, Centralized Control, Decentralized Control

[L] [BSL00] Bilimoria, Sheth, et al, "Performance Evaluation of Airborne Separation Assurance for Free Flight"
Key Words: Free Flight, CD&R, Geometric Optimization, Safety, Efficiency, Stability

[L] [BSC00]Bilimoria, Sridhar, et al, "FACET: Future ATM Concepts Evaluation Tool"
Key Words: Free Flight, Evaluation Tool, CD&R, Dynamic Density

[L] [CDM97] Carrigan, Dieudonne, and MacDonald, "Field Evaluations Move ATM System Toward Free Flight
Key Words: Free Flight, URET, Field Evaluation

[H] [CL99] Cashion and Lozito, "The Effects of Different Levels of Intent Information on Pilot Self Separation Performance"

Key Words: Free Flight, Separation Assurance, Intent, CDTI, en route, Human Factors

[M] [CMM97] Cashion, Mackintosh, McGann, and Lozito, "A Study of Commercial Flight Crew Self-Separation"
Key Words: Free Flight, Simulation Demonstration, Self-Separation, Traffic Density

[H] [CP99] Castano and Parasuraman, "Manipulation of Pilot Intent under Free Flight: A Prelude to Not-So-Free-Flight"
Key Words: Free Flight, Separation Assurance, Intent, Human Factors, ATC

[L] [CLM96] Chang, Livack, and McDaniel, "Emerging Cockpit Technologies for Free Flight"
Key Words: Free Flight, Technologies

[H] [CHO00]Cieplak, Hahn, and Olmos, "Safe Flight 21: The 1999 Operational Evaluation of ADS-B Applications"
Key Words: Free Flight, Operational Evaluation, ADS-B, CDTI, Workload, ATC, Pilot, Questionnaires

[L] [CS99]Colligan and Suchkov, "A Study of Aircraft Separation"
Key Words: Operational Data, Conflicts, Points of Closest Approach

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Key Words: Free Flight, CD&R, Multiple Aircraft Conflicts, Genetic Algorithms

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Key Words: Free Flight, Simulation Study, Empirical Results, Closely Spaced Parallel Approaches, CDTI

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Key Words: Free Flight, Intent, Shared Models, OPAL, CD&R

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Key Words: Free Flight, CD&R, Man-in-the-Loop Simulator Experiment

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Key Words: Free Flight, CD&R, Collision Avoidance, Human-Centered Design, Requirements

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Key Words: Free Flight, Index of Collision Risk, Airspace Complexity

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Key Words: Free Flight, CD&R, Tactical, Strategic, Alert Zones

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Key Words: Free Flight, CD&R, Tactical, Strategic, Alert Zones

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Key Words: Hazard Alerting, TCAS, SOC Curves

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Key Words: Hazard Alerting, TCAS, SOC Curves

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Key Words: Conflict Detection and Resolution, Survey

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Key Words: Free Flight, Flight Deck, Separation Assurance, ADS-B, Human Factors, Simulator Experiments

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Key Words: Free Flight, Displays, Perspective vs Coplanar, CDTI, Pilot Workload

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Key Words: Free Flight, CDTI, Weather Information, Traffic Information, Coplanar vs Perspective

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Key Words: Free Flight, Conflict Detection and Resolution, Safety, Probability

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Key Words: Free Flight, Conflict Detection and Resolution, Safety, Probability

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Key Words: Free Flight, Conflict Detection and Resolution, Simulation Experiment, Pilot Subjects

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Key Words: Free Flight, Conflict Detection and Resolution, Simulation Experiment, CDTI, Pilot Subjects

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Key Words: Free Flight, Separation Assurance, CD&R, Rules of the Road, Coordination

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Key Words: Free Flight, Self-Separation, Pilot, Experiment

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Key Words: Free Flight, Displays, CDTI, Pilot, Experiments, Perspective vs Co-Planar

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Key Words: Free Flight, Displays, CDTI, Pilot, Experiments, Perspective vs Co-Planar

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Key Words: Free Flight, CD&R, Intent Information, Probabalistic

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Key Words: Free Flight, CD&R, Literature Review, Potential Fields

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Key Words: Distributed Problem Solving, Negotiation, ATC, Protocols, Contract Net Protocol

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Key Words: Free Flight, CDM, ATC, FD, Route Negotiation, Weather, CD&R, Empirical Study

[L] [HMG99] Harper, Mulgund, Guarino, *et al*, "Air Traffic Controller Agent Model for Free Flight"
Key Words: Principled Negotiation, ATM, ATC, Collaborative Decision Making, CD&R

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Key Words: Principled Negotiation, ATM, agents, distributed systems

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Key Words: Principled Negotiation, ATC, distributed systems, agents, expert system

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Key Words: Principled Negotiation, ATC, distributed systems, agents, conflict detection and resolution

[H] [WMT96] Wickens, Miller, and Tham, “The Implications of Data-Link for Representing Pilot Request Information on 2D and 3D Air Traffic Control Displays”
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Key Words: Collaborative Decision Making, Decentralized Control, ATM, Free Flight, Flow Management

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Key Words: Collaborative Decision Making, Ground Delay Program, AOCnet, ETMS, OAG, Cost/Benefits

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Key Words: Collaborative Decision Making, Data Exchange, agent-based modeling, simulation, weather, gaming

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Key Words: Information Requirements, Free Flight, En Route ATC, Survey, ATC Subjects

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Key Words: Information Requirements, Free Flight, En Route ATC, Survey, ATC Subjects

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Key Words: Collaborative Decision Making, Collaborative Re-Routing, Weather Awareness, Experiment

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Key Words: Collaborative Decision Making, Time Critical Events, Weather, Replanning

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Key Words: Free Flight, CDM, ATC, FD, Route Negotiation, Weather, CD&R, Empirical Study

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Key Words: AOC, Operational Overview, National Routing Program, Data Exchange, Dynamic Route Planning

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Key Words: Data Exchange, CTAS, Free Flight, En Route, Terminal

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Key Words: Collaborative Decision Making, Visualization, Weather, Asynchronous Communication

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Key Words: Collaborative Decision Making, Visualization, Weather, Asynchronous Communication

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Key Words: Collaboration, Teleconferencing, e-mail, e-collaboration, groupware

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Key Words: CWIN, Display, Weather, Reroute Decisions, Simulator Flight Tests

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Key Words: Free Flight, ATM, Information Management, Roles and Responsibilities, Controller Comments

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Key Words: Collaborative Decision Making, Traffic Flow Management, War Gaming, User Experiments

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Key Words: Collaborative Arrival Planning, Data Exchange, CTAS

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Key Words: Collaborative Arrival Planning, Data Exchange, CTAS

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Key Words: Data Exchange, CTAS, Free Flight, En Route, Terminal

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Key Words: Data Exchange, CTAS, Terminal Area, Workload, Full Motion Simulator Experiments

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Key Words: Data Exchange, FMS, Terminal Area, Workload, Simulation

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Key Words: Collaborative Arrival Planning, CTAS, ATC

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Key Words: Weather Avoidance, Dijkstra's Algorithm

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Key Words: CTAS, Weather Avoidance, ETA

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Key Words: CTAS, Weather Avoidance, Snell's Law, Dijkstra's Algorithm

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Key Words: Weather Avoidance, ATC, Displays, Weather Vectoring, Empirical Study

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Key Words: Free Flight, Weather Avoidance, CDTI

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Key Words: Free Flight, CDTI, Weather Information, Traffic Information, Coplanar vs Perspective

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Key Words: Operational Data, Terminal Weather Avoidance

[H] [Sc94] Scanlon, "Cockpit Graphical Weather Information Shown to Enhance Efficiency, Safety, and Situation Awareness"
Key Words: CWIN, Display, Weather, Reroute Decisions, Simulator Flight Tests

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Key Words: Terminal Weather Avoidance, Pilot Survey, Questionnaire

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Key Words: Operational Data, Terminal Weather Avoidance

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Key Words: In-Trail Following, Simulation, Terminal Area, CD&R, Roles and Responsibilities

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Key Words: CDTI, In-Trail Following, Experimental, Simulation

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Key Words: In-Trail Following, Simulation, Control Laws

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Key Words: In-Trail Following, Simulation, Terminal Area, CD&R, Roles and Responsibilities

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Key Words: Closely-Spaced Parallel Approaches, CD&R, Collision Probabilities

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Key Words: Closely-Spaced Parallel Approaches, CD&R

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Key Words: Parallel Approach, CD&R, TCAS, AILS

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Key Words: Taxi Performance, Nonlinear Control, Automatic Control, Surface Movement

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Key Words: Surface Movement, Location, Surveillance, ADS-B, Tests

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Key Words: Surface Movement Advisor, Delays, Gates, Departures, Database Management

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Key Words: Surface Movement Advisor, Delays, Gates, Departures, Database Management

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Key Words: Human Factors, Gate-to-Gate Operations, Decision Support Tools, CTAS/TMA, Usability

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Key Words: Human Factors, Data Link, Communications

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Key Words: Communications, Data Link, Utilization, Delays

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Key Words: Human Factors, Data Link, Communications, Gate-to-Gate

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Key Words: Human Factor, Data Link, Communications, Gate-to-Gate, CD&R, Flight Plan Changes

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Key Words: Free Flight, Airspace Complexity, Dynamic Density, ATC, CD&R, Workload

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Key Words: Dynamic Density, Entropy, geometric complexity, ATC, CD&R

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Key Words: Free Flight, Index of Collision Risk, Airspace Complexity

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Key Words: Dynamic Density, Traffic Complexity, Human Factors, ATM, Workload

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Key Words: ATC, Complexity, Literature Review

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Key Words: Airspace Complexity

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Key Words: Complexity, ATC, Dynamic Density, conflict resolution

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Key Words: Airspace Complexity, Dynamic Density, ATC, conflict detection, Workload

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Key Words: Airspace Complexity, Review of Literature, Operational Errors, Human Factors

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Key Words: Free Flight, Human Factors, Requirements, Roles and Responsibilities

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Key Words: Free Flight, Management by Exception, Roles and Responsibilities, Controller and Pilot Interviews

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Key Words: Free Flight, National Routing Program, ATC, Roles, Control Authority

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Key Words: Free Flight, Pilots, Survey, Opinions, ATM

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Key Words: ATM, Roles, DSTs, Data Exchange, Workload

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Key Words: Free Flight, Roles and Responsibilities, CDTI Requirements, Operational Concept

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Key Words: Free Flight, Roles and Responsibilities, Operational Concept

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Key Words: Supervisory Control, Human-in-Charge, Intelligent Associate

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Key Words: Free Flight, Philosophies, Procedures, ATC, Traffic Flow Management

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Key Words: Free Flight, Human Factors, ATC, structure interviews, roles and responsibilities

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Key Words: Free Flight, Roles and Responsibilities, Air Traffic Controller, Workload, Experiment

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Key Words: Free Flight, Responsibilities, Irregular Operations, Field Study

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Key Words: Free Flight, Roles and Responsibilities, CDM, NRP, Management by Exception

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Key Words: Free Flight, ATM, Information Management, Roles and Responsibilities, Controller Comments

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Key Words: Free Flight, ATM, Information Management, Roles and Responsibilities

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Key Words: Control by Permission, ATC, Cooperative Problem Solving, Shared Understanding

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Key Words: Free Flight, Pilot’s Role, Experiments, Simulations

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Key Words: Free Flight, Operational Concept, Sector Loads, Conflicts, Alert Rates, Workload

[H] [CFL99] Corker, Fleming, and Lane, “Measuring Controller Reactions to Free Flight in a Complex Transition Sector”
Key Words: Free Flight, Human Factors, Experiments, Controller, Workload

[H] [CGF00]Corker, Gore, et al, “Free Flight and the Context of Control: Experiments and Modeling to Determine the Impact of Distributed Air-Ground Air Traffic Management on Safety and Procedures”
Key Words: Free Flight, Human Factors, Experiments, Controller, Workload

[H] [DCM99] Dunbar, Cashion, McGann, et al, “Air-Ground Integration Issues in a Self-Separation Environment”
Key Words: Free Flight, Human Factors, Empirical Study, Self-Separation, CD&R, Controllers, Pilots, Workload

[M] [En97]Endsley, “Situation Awareness, Automation, & Free Flight”
Key Words: Free Flight, Workload, Situation Awareness, ATC, Automation

[M] [EMS97] Endsley, Mogford, and Stein, “Effect of Free Flight on Controller Performance, Workload, and Situation Awareness”
Key Words: Free Flight, Controller, Performance, Workload, Situation Awareness

[H] [GDM98] Galster, Duley, et al, “Effects of Aircraft Self Separation on Controller Conflict Detection Performance and Workload in Mature Free Flight”
Key Words: Free Flight, Performance, Workload, Conflict Detection and Resolution

[H] [HBP97]Hilburn, Bakker, et al, “The Effect of Free Flight on Air Traffic Controller Mental Workload, Monitoring and System Performance”
Key Words: Free Flight, Performance, Workload, Conflict Detection and Resolution

[M] [H97] Hilburn, “Free Flight and Air Traffic Controller Mental Workload”
Key Words: Free Flight, ATC, Workload, Experiments

[H] [Ke00] Kerns, “An Experimental Approach to Measuring the Effects of a Controller Conflict Probe in a Free Routing Environment”
Key Words: Free Flight, Workload, ATC, Simulation, CD&R

[H] [KM98] Kerns and McFarland, “Conflict Probe Operational Evaluation and Benefits Assessment”
Key Words: Free Flight, CD&R, URET, ATC, Simulation

[M] [LS98] Lee and Sanford, “The Passive Final Approach Spacing Tool (pFAST) Human Factors Operational Assessment”
Key Words: CTAS, pFAST, Operational Assessment, Workload, Usability, Acceptance, Controllers

[M] [MMF00] Manning, Mills, Fox, et al“Investigations the Validity of Performance and Objective Workload Evaluation Research (POWER)”
Key Words: ATM, Controller Workload, Sector Complexity, System Performance

[H] [MW98] Morphew and Wickens, “Pilot Performance and Workload Using Traffic Displays to Support Free Flight”
Key Words: Free Flight, Pilot, Workload, Display

[H] [MGP99] Metzger, Galster, and Parasuraman, "Effects of a Conflict Detection Aid and Traffic Density on Controller Mental Workload and Performance in an ATC Task Simulating Free Flight"
Key Words: Free Flight, Workload, ATC, Simulation, CD&R

[L] [MP99] Metzger and Parasuraman, "Free Flight and the Air Traffic Controller: Active Control versus Passive Monitoring"
Key Words: Free Flight, Roles and Responsibilities, Air Traffic Controller, Workload, Experiment

[H] [PH98] Pekela and Hilburn, "Air Traffic Controller Strategies in Resolving Free Flight Traffic Conflicts: the Effect of Enhanced Controller Displays for Situation Awareness"
Key Words: Free Flight, ATC, Displays, Situation Awareness, Human Factors

[H] [RJR00] Remington, Johnston, Ruthruff, et al, "Visual Search in Complex Displays: Effects of Traffic Load, Regularity, and Conflict Geometry on the Detection of Conflicts by Air Traffic Controllers"
Key Words: Free Flight, ATC, Displays, Emperical Study, Conflict Detection

2.0 ANALYSIS AND COMPARISON OF RESEARCH

In this chapter, research efforts from the literature review are analyzed and compared. Research efforts are compared based several subjective and objective criteria including:

- Primary result or contribution of the research,
- Relevance to one or more triad category ATM/AOC/FD,
- Relevance to one or more DAG-TM Concept Elements CE 0 through CE 14,
- Relevance to one or more of the important Research Issues RI 1 through RI 12 of Free Flight,
- Approach: Observations based on operational data, Questionnaire, Fast-Time vs. Real-Time simulation, Human-in-the-loop simulation, Flight test, etc., and
- Major limitations or questionable assumptions of the research

At the end of the analysis, we identify research questions that are currently unanswered by the research efforts included in the literature review.

2.1 Research Synopses

Table 2. Synopsis for Research of Castano and Parasuraman.

[H] [CP99]	Castano and Parasuraman “ Manipulation of Pilot Intent under Free Flight: A Prelude to Not-So-Free-Flight”
Key Words: Free Flight, Separation Assurance, Intent, Human Factors, ATC	
Relevance: ATM; CE 5; RI 2, RI 5, RI 8, RI 11	**Approach**: PC-Based ATC Simulation, 12 Active En Route Air Traffic Controllers
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: (1) *“Air traffic controllers made more operational errors, predicted more conflicts than were scripted in the scenarios, and issued more clearances than were necessary to clear the scripted conflicts under high traffic/ low intent situation than under high traffic / medium intent situation.”* (2) *“The degrading influence of low intent was particularly severe under high traffic.”* (3) *“Acute-geometry conflicts became harder to detect as the level of intent went from medium to low*.” High Intent: Waypoints, flight plans, flight progress strips, airways Medium Intent: Waypoints and flight plans Low Intent: No waypoints or flight strips	
Limitations/Assumptions: Limitation: The high intent display manifested clutter. Assumption: High (16 aircraft) and Moderate (11 aircraft) traffic density over a 50-mile radius is representative of Free Flight conditions.	

Table 3. Synopsis for Research of Metzger, Galster, and Parasuraman.

<table>
<tr><td>H [MGP99]</td><td>Metzger, Galster, and Parasuraman
“Effects of a Conflict Detection Aid and Traffic Density on Controller Mental Workload and Performance in an ATC Task Simulating Free Flight”</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Workload, ATC, Simulation, Conflict Detection and Resolution</td></tr>
<tr><td>Relevance: ATM; CE 5; RI 2, RI 5, RI 8, RI 11</td><td>Approach: PC-Based ATC Simulation, 12 Active En Route Air Traffic Controllers</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:

(1) “A conflict detection aid improved ATC detection of conflicts and self separations. ATC detected about 40% more conflicts and self-separations and did so about 60 seconds earlier when they were supported by the aid than when the aid was not present. However, even with the support of a 100% reliable detection aid, ATC missed a high percentage of events. Under high traffic density, close to 50% of the self-separations and about 20% of the conflicts were missed when the aid was available.”

(2) “Mental workload was affected by traffic density.”

(3) “The presence or absence of the conflict detection aid had no effect on workload.”

<u>Independent Variables</u>: (1) presence or absence of a conflict detection aid (2) moderate or high traffic density.
<u>Dependent Variables</u>: Response time to correctly identify conflicts; missed actions; false alarms.
<u>Dependent Measures</u>: (1) secondary task performance on mental workload and (2) subjective ratings of mental workload (NASA-TLX)</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: While objective measures showed a benefit for automation, subjective ratings suggested the opposite.

<u>Limitation</u>: The authors speculate: “controllers might have felt that the 5-minute look-ahead time of the alert would not give them enough time to resolve a conflict and therefore did not rely on it.”

<u>Assumption</u>: High (17 aircraft) and Moderate (11 aircraft) traffic density over a 50-mile radius is representative of Free Flight conditions.

<u>Assumption</u>: A 5-minute conflict probe was used.</td></tr>
</table>

Table 4. Synopsis for Research of Galster, Duley, et al.

<table>
<tr><td>[H] [GDM98]</td><td>Galster, Duley, Masalonis, and Parasuraman
“ Effects of Aircraft Self Separation on Controller Conflict Detection Performance and Workload in Mature Free Flight”</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Performance, Workload, Conflict Detection and Resolution</td></tr>
<tr><td>Relevance: ATM; CE 5; RI 2, RI 5, RI 11</td><td>Approach: Man-in-the-loop ATC Simulation, 10 Active Air Traffic Controllers; NASA TLX</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) “When conflicts were not present, controllers reported significantly higher subjective workload under the high traffic condition compared to the moderate traffic condition.”
(2) “In saturated airspace, Air Traffic Controllers had difficulty both in detecting conflicts and in recognizing self-separating events in a timely manner.”
(3) “In the moderate traffic condition 10% of conflicts were not reported prior to loss of separation. In the high traffic condition the miss rate climbed to 50%..”
(4) “In saturated airspace, Air Traffic Controller workload increased, as indexed both by subjective and secondary-task measures.”</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: “Controllers in the present simulation study were required to monitor under very high traffic loads, did not have intent information, and were not provided any automation support tools.”
<u>Limitation</u>: A generic airspace was used for all experiments.
<u>Assumption</u>: High (17 aircraft) and Moderate (11 aircraft) traffic density over a 50-mile radius is representative of Free Flight conditions.
<u>Assumption</u>: “The controller operated primarily as a monitor of the airspace, as would be the case in mature Free Flight.”</td></tr>
</table>

Table 5. Synopsis for Research of Dunbar, Cashion, McGann, et al.

[H] [DCM99]	Dunbar, Cashion, McGann, et al " Air-Ground Integration Issues in a Self-Separation Environment"
Key Words: Free Flight, Human Factors, Empirical Study, Self-Separation, CD&R, Controllers, Pilots, Workload	
Relevance: ATM, FD; CE 5, CE 6; RI 1, RI 2, RI 5	**Approach**: Man-in-the-loop ATC and Pilot Simulation, 10 flight crews, 10 Active Air Traffic Controllers; Questionnaires
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: (1) *"Flight crews took significantly longer to detect conflicts in the high density conditions as compared to low density conditions."* (2) *"Crews detected a conflict prior to the alert 95% of the time."* (3) *"For the obtuse angle conflict, crews took significantly longer both to initiate a maneuver in high density traffic and were more likely to maneuver after the alert vs. prior to the alert."* (4) *"Pilots spent more time viewing a smaller map range (80 nm) in high density conditions compared to the low density conditions for all scenarios. Conversely, more time was spent at the larger 160 nm range in the low density conditions than in the high density conditions."* (5) *"Controller participants took significantly longer to detect the obtuse angle conflict in the high density condition as compared to the low density condition."* (6) *"Controllers detected the acute angle conflict significantly more quickly than either the right or obtuse angle conflict in the high density condition."* (7) *"The ownship contacted the intruder 81% of the time. Furthermore, for 38 of the 46 runs in which the intruder was contacted, the communication occurred prior to any airborne alert."* (8) *"In the post-experiment questionnaire, all ten controller participants stated that they would want to be informed of all maneuvers the flight crew was making prior to the crew initiating the maneuver."* (9) *"Both crews and controllers indicated an increased workload in the high density conditions over low density conditions."*	
Limitations/Assumptions: Limitation: No winds or turbulence were present; no weather was present, no SUA, and no abnormal situations. Limitation: There was no ground-based alerting logic represented in the study. Assumption: Low traffic density was 7-8 aircraft and high was 15-16 aircraft. Assumption: The airborne alerting logic overlaid the simulator's TCAS logic	

Table 6. Synopsis for Research of Kerns and McFarland.

H [Ke00]	Kerns "An Experimental Approach to Measuring the Effects of a Controller Conflict Probe in a Free Routing Environment"
H [KM98]	Kerns and McFarland "Conflict Probe Operational Evaluation and Benefits Assessment"

Key Words: Free Flight, Workload, ATC, Simulation, CD&R

Relevance: ATM; CE 5; RI 2, RI 5, RI 8, RI 11	**Approach**: Man-in-the-loop ATC Simulation, 12 Air Traffic Controllers; CARS, TLX Ratings

Main Contributions: Free Flight scenarios were evaluated in simulation with main results:

(1) *"This study found no evidence of safety problems under any of the test conditions."*

(2) *"Changes in traffic conditions representing the introduction of unstructured routings and higher traffic loads significantly affected controller workload. The pattern of workload impacts differed for R and D controllers indicating that changes in traffic structure are more likely to affect the R controller's tactical role while changes in traffic load are more likely to affect the D controller's strategic role.*"

(3) *"The significant main effect of traffic condition is evident in the increased level of altitude resolution maneuvers in the unstructured and high volume unstructured conditions as compared to the structured conditions.*"

(4) *"Both the subjective and objective workload results of this study indicate that conflict probe automation tended to reduce workload under the high volume unstructured traffic condition."*

Independent Variables: (1) baseline structured traffic (2) unstructured traffic, and (3) unstructured traffic with increased volume.
Dependent Measures: (1) Aircraft separation violations, (2) supervisor safety assessment, (3) controller operational acceptability rating (CARS), (4) controller workload (NASA TLX).

Limitations/Assumptions:
Limitation: As stated by the authors: "*The subjective and objective measures tended to disassociate. The objective workload measure indicated increased controller workload under unstructured traffic conditions while the subjective measure indicated reduced workload under unstructured traffic conditions."*

Limitation*: "Controller feedback during the simulation suggested that lateral maneuver options were constrained in the unstructured conditions by the random locations of surrounding traffic."*

Assumption: Controllers were familiar with URET.

Table 7. Synopsis for Research of Corker, Fleming, et al.

[H] [CFL99] [H] [CGF00]	Corker, Fleming, and Lane “Measuring Controller Reactions to Free Flight in a Complex Transition Sector” Corker, Gore, Fleming, and Lane “Free Flight and the Context of Control: Experiments and Modeling to Determine the Impact of Distributed Air-Ground Air Traffic Management on Safety and Procedures”
Key Words: Free Flight, Workload, ATC, Simulation, CD&R, Intent Information	
Relevance: ATM; CE 5; RI 2, RI 5, RI 8, RI 11	**Approach**: Man-in-the-loop ATC Simulation, 8 Air Traffic Controllers; Questionnaire
Main Contributions: The following Free Flight scenarios were evaluated in simulation: (1) traditional ground-based control, (2) traditional control but with all aircraft flying direct, (3) all aircraft flying direct with 20% self-separating, and (4) all aircraft flying direct with 80% self-separating. The experiments had the main results: (1) *“The controller operating in conditions of extensive self-separating operations finds the task of monitoring that traffic workload intensive, independent of the communication tasks usually associated with positive air traffic control.”* (2) *“Under the conditions of this experiment, we have moved controllers from a situation in which they have strategic management and information (full positive control), to one in which they are fundamentally reactive, or opportunistic. … When tactical intent information became less and less available, controllers perceived their workload to be higher and higher*.” (3) *“Presentation of intent information for free flying aircraft was highly desired by the participants”*	
Limitations/Assumptions: <u>Limitation</u>: As stated by the authors: “*In these experiments the process of self-separation did not provide future or aircraft “intent” information to the controller. In that mode, the amount of past or future information that can be taken into account by the controller is minimal.”*	

Table 8. Synopsis for Research of Hilburn, et al.

<table>
<tr><td colspan="2">[H] [HBP97] Hilburn, Bakker, Pakela, and Parasuraman
"The Effect of Free Flight on Air Traffic Controller Mental Workload, Monitoring and System Performance"
[H] [PH98] Pekela and Hilburn
"Air Traffic Controller Strategies in Resolving Free Flight Traffic Conflicts: the Effect of Enhanced Controller Displays for Situation Awareness"</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Controller Workload, Empirical Study, Simulation, Human Factors</td></tr>
<tr><td>Relevance: ATM; CE 5; RI 2, RI 5, RI 11</td><td>Approach: (1) Man-in-the-loop ATC Simulation, 10 Military Controllers; Questionnaire, ANOVA; (2) Man-in-the-loop ATC Simulation; 7 Military Controllers; Questionnaire</td></tr>
<tr><td colspan="2">Main Contributions: The following Free Flight scenarios were evaluated in simulation:
(1) traditional ground-based control,
(2) Free Flight with intent sharing between aircraft and ATC, and
(3) Free Flight with no intent sharing between aircraft and ATC.
The experiments had the main results:
(1) Greater amounts of traffic increased visual workload.
(2) "Controllers generally found Free Flight surprisingly easy, and reported that workload was much lower than they had anticipated."
(3) "Controllers felt strongly that aircraft intentions should always be available to the controller"
(4) Experiments did not include a strategic conflict detection tool, and "most controllers felt that conflict detection was more difficult under Free Flight."
(5) "Several controllers also volunteered that if aircraft had been free to communicate their intent to both ATC and to other aircraft, ATC could become safer and easier."
Further experiments including a CD&R tool and a CDTI for the controller revealed:
(6) "controllers tended to rely more on the vertical view than the plan view portion of the CDTI, as a tool for monitoring aircraft self-seperation."
(7) "Under high traffic, controllers reported reverting to the PVD alone."
(8) "data suggest that a Free Flight conflict probe for air traffic controllers should have a look ahead capability of well over five minutes."</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Assumption</u>: Traffic density for the first set of experiments were 10 and 17 aircraft; traffic densities for the second set of experiments were 2, 4, and 10 aircraft.
<u>Assumption</u>: The second set of experiments assumed "a mature Free Flight scenario, in which (1) all aircraft were equipped with ADS-B and can broadcast altitude, speed, rate of climb/descent, and ground track, and (2) both air and ground have identical conflict detection and resolution algorithms."</td></tr>
</table>

Table 9. Synopsis for Research of Remington, Johnston, et al.

<table>
<tr><td>H [RJR00]</td><td colspan="2">Remington, Johnston, et al
“Visual Search in Complex Displays: Effects of Traffic Load, Regularity, and Conflict Geometry on the Detection of Conflicts by Air Traffic Controllers”</td></tr>
<tr><td colspan="3">Key Words: Free Flight, ATC, Displays, Empirical Study, Conflict Detection</td></tr>
<tr><td colspan="2">Relevance: ATM; CE 5; RI 2, RI 5, RI 8, RI 11</td><td>Approach: PC-Based ATC Man-in-the-Loop Simulation, 4 Air Traffic Controllers; Questionnaire</td></tr>
<tr><td colspan="3">Main Contributions: Free Flight scenarios were evaluated in simulation for fixed routes (present vs absent) and with altitude restrictions (present vs absent) with main empirical results:
(1) “Traffic load and conflict geometry had large effects on conflict detection times; there was a 400% increase from the easiest to most difficult condition (8 seconds to 33 seconds).”
(2) “Removal of route restrictions had very litter detrimental effect (<2 seconds); in some cases the net effect was actually positive.”
(3) “The presence of altitude restrictions led to a small reduction in detection time, especially when the time to conflict was short.”
(4) “Color-coding of altitude significantly reduced conflict detection times (approximately 30%).”
(5) “Performance with history markers was roughly equivalent to performance with aircraft symbols oriented to aircraft track (i.e. wedges).”
The conclusions of the authors are:
(1) “Our experiments provided no evidence that relaxing route restrictions will impair conflict detection.”
(2) “Removing altitude restrictions had only a small effect on conflict detection time.”
(3) “Use of non-oriented aircraft symbols together with track history to depict direction of travel (current practice) did not produce a large overall drop in performance, but the use of oriented aircraft icons would appear to have special advantages for Free Flight. Color-coding altitude, or providing an equivalent perceptual cue, might provide even more substantial benefits under Free Flight."</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: The authors state: “We are careful to restrict our conclusion to the detection of horizontal traffic conflicts, and do not extend it to other controller tasks.”
<u>Assumption</u>: Routes were straight line paths.</td></tr>
</table>

Table 10. Synopsis for Research of Smith, McCoy, Orasanu, et al.

<table>
<tr><td colspan="2">H [SMO97]</td><td colspan="2">Smith, McCoy, Orasanu, et al
“Control by Permission: A Case Study of Cooperative Problem Solving in the Interactions of Airline Dispatchers with ATCSCC”</td></tr>
<tr><td colspan="4">Key Words: Control by Permission, ATC, Cooperative Problem Solving, Shared Understanding</td></tr>
<tr><td colspan="2">Relevance: ATM, AOC; CE 0, CE 5, CE 6, CE 7, CE 8, RI 2, RI 3, RI 4, RI 12</td><td colspan="2">Approach: Interviews, 8 Dispatchers, 2 ATC Coordinators</td></tr>
<tr><td colspan="4">Main Contributions: As a step towards Free Flight, current experience with the National Routing Program (NRP) were used to evaluate the concept of control by permission, a new procedure appropriate for Free Flight. Results of the study are: “Four factors were identified as contributing to successful cooperative problem solving:
(1) development of a shared understanding of goals, problems, constraints, and solutions,
(2) distribution of responsibilities to a number of different individuals,
(3) incorporation of feedback and process control loops into the system, and
(4) staff selection.”</td></tr>
<tr><td colspan="4">Limitations/Assumptions:
<u>Limitation</u>: It may not be valid to extrapolate experience with the NRP to draw conclusions about Free Flight.
<u>Limitation</u>: Conclusions drawn from interviews may not be as scientifically significant compared to controlled empirical experiments.
<u>Limitation</u>: As stated by the authors: “Some caution should be applied in interpreting these results, since they are based primarily on a single 7-hour meeting.”</td></tr>
</table>

Table 11. Synopsis for Research of Duley, Galster, et al.

<table>
<tr><td colspan="2">[H] [DGP99] Duley, Galster, Parasuraman, and Smoker
"En Route ATC Information Requirements for Participation in Future Collaborative Decision Making"
[M] [DGP98] Duley, Galster, and Parasuraman
"Information Manager for Determining Data Presentation Preferences in Future Enroute Air Traffic Management"
[M] [DGM97] Duley, Galster, Masalonis, et al
"En Route Controller Information Requirements from Current ATM to Free Flight"</td></tr>
<tr><td colspan="2">Key Words: Collaborative Decision Making, Information Requirements, Human Factors, Human-Centered</td></tr>
<tr><td>Relevance: ATM, AOC; CE 0, CE 5, CE 6, CE 7, CE 8, RI 2, RI 3, RI 4, RI 12</td><td>Approach: Survey; 58 En Route Controllers</td></tr>
<tr><td colspan="2">Main Contributions: A survey was taken to identify the information requirements for a Free Flight air traffic control interface with results:
(1) "Controllers vary in their presentation preferences"
(2) "Controllers perform their tasks concurrently rather than sequentially"
(3) "Controllers' information requirements are task dependent"
(4) "Controllers need context in determining their information requirements."</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: The authors note that survey population "is unfamiliar with Free Flight, the automation tools being proposed, and the potential impact on their role within the NAS."</td></tr>
</table>

Table 12. Synopsis for Research of Farley, Hansman, Endsley, et al.

<table>
<tr><td>[H] [FHE98]</td><td colspan="2">Farley, Hansman, Endsley, et al
“The Effect of Shared Information on Pilot/Controller Situation Awareness and Re-Route Negotiation”</td></tr>
<tr><td colspan="3">Key Words: Free Flight, CDM, ATC, FD, Route Negotiation, Weather, CD&R, Empirical Study</td></tr>
<tr><td colspan="2">Relevance: FD; ATM, CE 6, CE 7; RI 1, RI 2, RI 4, RI 5, RI 6, RI 8, RI 11, RI 12</td><td>Approach: Simulation, 5 Pilots, 5 Controllers; Questionnaires, NASA-TLX</td></tr>
<tr><td colspan="3">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) “Controller situation awareness with respect to weather improves” when both the FD and ATC share the same weather information.
(2) “Pilots’ traffic situation awareness improves” when both the ATC and FD share the same traffic information.
(3) “The availability of shared information did not affect the workload in any systematic way”
(4) “With datalink enabled, the pilot and controller made more voluntary suggestions to one another for specific route adjustments. This verbal exchange of re-routing ideas, options, and preferences was rarely evident in the baseline configuration and is statistically significant.”
<u>Baseline</u>: The datalink was disabled and no sharing of weather information was in common between ATC and FD; the FD did have a weather displayed but no traffic information; ATC had traffic information but no weather information.
<u>Datalink Enabled</u>: The same weather and traffic information was shared between ATC and FD</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: “the test matrix was unbalanced, as three subject pairs performed the baseline configuration first while two subject pairs performed the “datalink enabled” configuration first.”
<u>Limitation</u>: It is unlikely a cockpit display will have weather data and no traffic data, so the baseline does not model current or future situations.</td></tr>
</table>

Table 13. Synopsis for Research of Barhydt and Hansman, Jr.

H [BH99]	Barhydt and Hansman, Jr. *Experimental Studies of Intent Information on Cockpit Traffic Displays*
Key Words: Free Flight, Pilot, CDTI, Intent, Experiment, Conflict Detection and Resolution	
Relevance: FD; CE 3, CE 5; RI 1, RI 5, RI 6, RI 11	**Approach**: Flight Simulation, 8 Commercial Airline Pilots, 5 Scenarios, 4 Displays; Pilot Questionnaire
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: "*Pilots maneuvered earlier and had fewer separation violations with the three enhanced displays*" and "*Providing intent information directly on the display or incorporating it into a conflict probe both led to fewer separation violations and earlier maneuvers compared to the basic TCAS display*". The 4 Displays evaluated were: Display 1: TCAS Display Display 2: Rate Display (Coplanar: split display with plan view and profile) – includes intruder current heading and altitude rate and conflict bands along ownship velocity vector Display 3: Commanded-State Display (Coplanar) – includes intruder current and commanded heading, commanded altitude and conflict bands along ownship velocity vector Display 4: FMS-path Display (Coplanar) – includes intruder FMS-path waypoints with relative altitude at waypoints and conflict bands along ownship velocity vector	
Limitations/Assumptions: Limitation: Only light (6 aircraft) traffic was used in scenarios; as the amount of information displayed increases, as with the FMS-path display, the CDTI may become cluttered; 63% of the pilots found the FMS-path display to be too cluttered. Limitation: Some of the results were not statistically significant and others marginally statistically significant Limitation: A 2-minute conflict probe was used, which is much shorter than most researchers expect for Free Flight Assumption: Pilots had full responsibility for maintaining separation and were free to maneuver at any time Assumption: Experiments assumed that a flawless datalink system was available between aircraft.	

Table 14. Synopsis for Research of Funabiki et al.

<table>
<tr><td colspan="2">[H] [FTS99] Funabiki, Tenoort, and Schick
"Traffic Information Display Enhancing Pilot Situation Awareness: PARTI"</td></tr>
<tr><td colspan="2">Key Words: Free Flight, CDTI, Human Factors, Experiment, ADS-B, Flight Plan Information</td></tr>
<tr><td>Relevance: FD; CE 5; CE 6, RI 1, RI 5, RI 6, RI 11</td><td>Approach: Flight Simulation, 8 Pilots; Questionnaire</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) "Most of the subjects reported that they could easily recognize the intentions of other aircraft through their displayed planned trajectories"
(2) "All subjects considered that the display improved their situation awareness"
(3) "Subjects gave significantly more correct responses to identification of conflicts with aircraft other than the nearest"
(4) "Overall, for catch-up and merging conflicts, subjects preferred to make speed changes, whereas for head-on conflicts, initiating a turn was the procedure most frequently chosen."
(5) "More than twice as many primary conflicts were correctly reported for the PARTI condition than for TCAS"
<u>Display 1</u>: TCAS Display
<u>Display 2</u>: PARTI Display</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: "Pilots quoted that the display sometimes contained too much information."
<u>Assumption</u>: Aircraft follow 4D flight trajectories
<u>Assumption</u>: Traffic information is shared between ATC and Pilot
<u>Assumption</u>: CD&R can be initiated by either the pilot or ATC
<u>Assumption</u>: An on-board CD&R system exists; CD&R based on constant velocity assumption
<u>Assumption</u>: Flight plans are determined through trajectory negotiation between ATC and pilot</td></tr>
</table>

Table 15. Synopsis for Research of Cashion and Lozito.

<table>
<tr><td>[H] [CL99]</td><td colspan="2">Cashion and Lozito
"The Effects of Different Levels of Intent Information on Pilot Self Separation Performance"</td></tr>
<tr><td colspan="3">Key Words: Free Flight, Separation Assurance, Intent, CDTI, en route, Human Factors</td></tr>
<tr><td colspan="2">Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11</td><td>Approach: Flight Simulation, 18 Crews, Questionnaire</td></tr>
<tr><td colspan="3">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) Altitude maneuvers were selected most often for resolving conflicts.
(2) "Crews rated FMC intent as slightly more useful for detecting conflicts than velocity vector intent"
(3) "The FMC display was rated more cluttered than both the MCP and velocity vector displays."
(4) "most crews still preferred the FMC condition even with the associated clutter."
(5) "No differences were found among these conditions when examining losses of separation, communication and maneuvering data."
<u>Display 1</u>: Velocity Vector Display
<u>Display 2</u>: Mode Control Panel Display
<u>Display 3</u>: Flight Management Computer Display</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: "The density of traffic was low (6 to 8 aircraft)."
<u>Assumption</u>: The alerting logic "overlaid the simulator's TCAS logic with the goal of creating a seamless relationship between the airborne alerting logic and TCAS."</td></tr>
</table>

Table 16. Synopsis for Research of Lozito, McGann, et al.

[H] [LMM97]	Lozito, McGann, Mackintosh, and Cashion "Free Flight and Self-Separation from the Flight Deck Perspective"
Key Words: Free Flight, Flight Deck, Separation Assurance, ADS-B, Human Factors, Simulator Experiments	
Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11	**Approach**: Flight Simulation, 10 Crews
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: (1) *"Most of the data evaluated in this study do not indicate performance differences between the low and high traffic density conditions."* (2) *"The ADS-B range portrayed traffic on the display within approximately 120 nm in front and to the side of the ownship. Although the participants most often selected the 160 nm range for the display, they were more likely to use a range of 80 nm on the navigation display in high density than in low density (in low density the were more likely to select 160 nm)."* (3) *"the data indicates a high likelihood of intercrew communication. It was very common for the participants to contact the intruder aircraft at least once."* (4) *"Heading changes were used most often for conflict resolution, then speed changes, then altitude changes."*	
Limitations/Assumptions: Limitation: No winds or turbulence were present; no weather was present. Limitation: The traffic volume and patterns were derived from current Denver Center sector data which may not represent Free Flight conditions. Assumption: Low traffic density was 7-8 aircraft and high was 15-16 aircraft. Assumption: The airborne alerting logic overlaid the simulator's TCAS logic.	

Table 17. Synopsis for Research of NASA/Honeywell.

<table>
<tr><td>[H] [EP00]</td><td>Elliott and Perry
"NASA Research for Instrument Approaches to Closely Spaced Parallel Runways"</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Simulation Study, Empirical Results, Closely Spaced Parallel Approaches, CDTI</td></tr>
<tr><td>Relevance: FD; CE 11, CE 12, CE 13, RI 1, RI 5, RI 6, RI 11, RI 12</td><td>Approach: Simulation Study, Flight Evaluation, 16 Commercial Pilots; MANOVA, questionnaires</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation and flight testing with main results:
(1) "A total of 55% of the respondents did not think the autopilot slowed their response to the emergency escape maneuver."
(2) "pilots will respond to the AILS (Airborne Information for Lateral Spacing) alerts in approximately 1 second whether the distance between the runways is 3400 ft. or 2500 ft."
(3) "The distance the aircraft closed on each other before they broke out of the approach was not affected by flight control mode or runway separation."</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: As stated by the authors: "Although the flight data set was not meant to be a statistically valid sample, the trends acquired in flight followed those of the simulator and therefore met the intent of validating the findings from the simulator."</td></tr>
</table>

Table 18. Synopsis for Research of Avans and Smith.

<table>
<tr><td colspan="2">[H] [AS97] Avans and Smith
"Experimental Investigations of Pilot Workload in Free Flight"</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Pilot, CDTI, Mental Workload</td></tr>
<tr><td>Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11</td><td>Approach: Flight Simulation, 12 Commercial Airline Pilots</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) "The estimation of the speed of the other aircraft and the time to contact proved to be a challenge and to produce high levels of cognitive effort."
(2) "Pilots had the most difficulty with scenarios where they were being overtaken by another aircraft".
(3) "Effort consistently increased when the color of an aircraft in the CDTI changed to indicate closer proximity." Also, "Effort consistently decreased when the color of an aircraft indicated that separation had increased."
<u>Display 1</u>: Color coded based on proximity to neighboring aircraft
<u>Display 2</u>: No color coding.</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Assumption</u>: The pilot and intruders were at level flight during the experiments.
<u>Assumption</u>: Low density was less than or equal to 8 aircraft and high density was 11or more.</td></tr>
</table>

Table 19. Synopsis for Research of Scallen, Smith, and Hancock.

H [SSH96] H [SSH97] Scallen, Smith, and Hancock "Pilot Actions During Traffic Situations in a Free Flight Airspace Structure" "Influence of Color Cockpit Displays of Traffic Information on Pilot Decision Making in Free Flight"
Key Words: Free Flight, Conflict Detection and Resolution, Simulation Experiment, Pilot Subjects
Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11 — **Approach**: Simulation, 15 Commercial Airline Pilots; 12 Commercial Airline Pilots
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: (1) *"Density and bearing did not appear to have any substantive effect on pilot response."* (2) *"Overtaking conflicts produced a higher frequency of operational errors than crossing or converging conflicts."* (3) *"Distance-based color coding of intruder aircraft on a CDTI did not increase pilots' ability to maintain separation in Free Flight scenarios."* (4) *"Pilots employing the color CDTI executed initial maneuvers earlier than pilots without color CDTI."* (5) *"In general, pilots executed more vertical maneuvers than other maneuver types."* Display 1: Color coded based on proximity to neighboring aircraft Display 2: No color coding.
Limitations/Assumptions: Limitation: The study only considered bearings of 90°, 45 °, and 0 °. Assumption: Low density was less than or equal to 8 aircraft and high density was 11or more.

Table 20. Synopsis for Research of Johnson, Battiste, and Holland-Bochow.

[H] [JBB99]	Johnson, Battiste, and Holland-Bochow "A Cockpit Display Designed to Enable Limited Flight Deck Separation Responsibility"
Key Words: Free Flight, CD&R, Empirical Study, Intent, Self Separation, CDTI	
Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11	**Approach**: Level D Flight Simulator, 8 Crews (16 participants); Questionnaire
Main Contributions: Free Flight scenarios were evaluated in simulation with main results: (1) *"Crews were very enthusiastic about the inclusion of 3-D flight plans."* (2) *"The use of altitude color-coding within both the traffic symbology and the flight plans was uniformly liked."* (3) *"Crews sometimes felt that there were just too many aircraft, and that this obscured important information."*	
Limitations/Assumptions: Assumption: No weather and no winds affect the aircraft in the experiments. Assumption: Error-free surveillance information is available to the CDTI. Assumption: No secondary tasks were given to the pilots (low workload).	

Table 21. Synopsis for Research of Johnson, Liao, and Tse.

<table>
<tr><td>[H] [JLT99]</td><td colspan="2">Johnson, Liao, and Tse
“The Effect of Symbology Location and Format on Attentional Deployment within a Cockpit Display of Traffic Information”</td></tr>
<tr><td colspan="3">Key Words: Target Detection, CDTI, CD&R, Highlighting</td></tr>
<tr><td colspan="2">Relevance: FD; CE 5, RI 1, RI 5, RI 6, RI 11</td><td>Approach: Computer Simulator, 8 University students; ANOVA</td></tr>
<tr><td colspan="3">Main Contributions: Scenarios were evaluated in simulation with main results:
(1) “Participants had biases to attend to different display locations in a visual search task.”
(2) “The left-right bias in the altitude detection task suggests that a natural left to right reading tendency may be influencing performance.”
(3) “Brightness appeared to have no effect on attracting participants’ initial attention.”
<u>Task 1</u>: Altitude Detection Task – search for the other aircraft that is at the same flight level
<u>Task 2</u>: Collsion Detection Task – search for the other aircraft that is on a collision course with ownship
<u>Task 3</u>: Collision Evaluation Task – identify if a given aircraft is in conflict with ownship</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: “the present experiment did not test other types of highlighting such as blinking or color.”
<u>Limitation</u>: University students were used as subjects, and they may not represent the pilot population.
<u>Assumption</u>: “Participants were told to assume that all aircraft flew at the same speed.”</td></tr>
</table>

Table 22. Synopsis for Research of NLR.

<table>
<tr><td>M [HvGR96], H [HvGR98]
H [HvGR99],</td><td colspan="2">Hoekstra, , van Gent, and Ruigrok
"Conceptual Design of Free Flight with Airborne Separation Assurance"
"Man-in-the-Loop part of a Study Looking at a Free Flight Concept"
"Designing for Safety: the 'Free Flight' Air Traffic Management Concept"</td></tr>
<tr><td colspan="3">Key Words: Free Flight, CD&R, Man-in-the-Loop Simulator Experiment</td></tr>
<tr><td colspan="2">Relevance: FD; CE 5; RI 1, RI 5, RI 6, RI 11</td><td>Approach: Man-in-the-loop Simulation, 8 Flight Crews; Questionnaires, RSME Scale</td></tr>
<tr><td colspan="3">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) "None of the experimental runs resulted in a loss of separation, except for the non-normal runs in which loss of separation was forced."
(2) "The experienced workload under Free Flight conditions with the Airborne Separation Assurance System (ASAS) as described is comparable to the workload in controlled flight during cruise, even when the traffic density is high."
(3) "None of the studies could refute the feasibility of an Airborne Separation Assurance concept for a future Free Flight environment."</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: No intent information was incorporated in the CDTI; Flight crews commented that "Some form of obtaining intent information should be made available."
<u>Assumption</u>: Traffic density was set to Single, Double, and Triple the "normal" density of European airspace to represent Free Flight traffic densities.
<u>Assumption</u>: A Coplanar (split display with plan view and profile) was used as the CDTI.
<u>Assumption</u>: A 5-minute conflict probe was used.
<u>Assumption</u>: The study was limited to en route flight.</td></tr>
</table>

Table 23. Synopsis for Research of Wickens, Carbonari, Merwin, et al.

<table>
<tr><td colspan="2">[H] [WCM97] Wickens, Carbonari, Merwin, et al
Cockpit Displays to Support Hazard Awareness in Free Flight
[H] [OW97] O'Brian and Wickens
"Free Flight Cockpit Displays of Traffic and Weather Information: Effects of Dimension and Data Base Integration"
[H] [MOW97] Merwin, O'Brien, and Wickens
"Perspective and Coplanar Representation of Air Traffic: Implications for Conflict and Weather Avoidance"</td></tr>
<tr><td colspan="2">Key Words: Free Flight, Displays, CDTI, Pilot, Experiments, Perspective vs Co-Planar, Weather</td></tr>
<tr><td>Relevance: FD; CE 5, CE 9; RI 1, RI 5, RI 6, RI 11</td><td>Approach: Man-in-the-loop Simulation, 30 Pilots (Experiments 1) 17 Pilots (Experiment 2); 15 Pilots (Experiment 3)</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation with main results:
(1) When a Coplanar (split display with plan view and profile) vs a Perspective display (with 30º elevation viewing angle) was compared, "Results reveal an advantage for the coplanar display, particularly when there was vertical intruder behavior."
(2) When a Coplanar vs a Perspective display format was compared, "Measures of flight safety favored the coplanar display, in terms of actual traffic conflicts, predicted traffic conflicts, and weather conflicts."
(3) "Across all displays and conflict geometries, pilots chose to maneuver vertically more than laterally."
(4) "The most pronounced effect revealed by the data appeared to be the negative effect of 3D ambiguity."
(5) "Trials which required the integration of both weather and traffic were best served by the displays in which traffic and weather were overlaid within the same panel."
(6) "Predictor elements were both found to improve safety (reduce actual and predicted conflicts) and to reduce workload, although the different elements affected workload in different ways."
<u>Experiment 1</u>: A Coplanar vs a Perspective display format (with 30º elevation viewing angle) was compared for the detection of traffic conflicts.
<u>Experiment 2</u>: A Coplanar vs a Perspective display format (with 30º elevation viewing angle) was compared for the detection of weather hazard conflicts.
<u>Experiment 3</u>: A Coplanar display was used to compare two predictive elements, an intruder predictor and a threat vector.</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: Experiments included only one or two intruder aircraft; results do not incorporate traffic densities expected for future Free Flight scenarios.
<u>Limitation</u>: As stated by the authors: "pilots were more familiar with 2D displays which are most often used in the aviation community." Also, "Perhaps the 2D advantage could be overcome with training."
<u>Limitation</u>: The paper does not fully describe the details of the two predictive elements compared.
<u>Limitation</u>: The 45 second predictor is quite short for Free Flight scenarios.
<u>Assumption</u>: A 45 second predictor span was used to predict future motion of aircraft.</td></tr>
</table>

Table 24. Synopsis for Research of Merwin and Wickens.

[H] [MW96]	Merwin and Wickens *Evaluation of Perspective and Coplanar Cockpit Displays of Traffic Information to Support Hazard Awareness in Free Flight*
Key Words: Free Flight, Displays, Perspective vs Coplanar, CDTI, Pilot Workload	
Relevance: FD; CE 3, CE 5; RI 1, RI 5, RI 6, RI 11	**Approach**: Man-in-the-loop Simulation, 30 Pilots; ANOVA evaluation
Main Contributions: Free Flight scenarios were evaluated in simulation. Two perspective displays, one with a 30° elevation viewing angle and the other with a 60° elevation viewing angle, were contrasted with a coplanar (split display with plan view and profile). The main results of this experimentation are: *(1) "The coplanar display supported performance in all measures that we equal to or greater than either of the perspective displays (i.e., fewer predicted and actual conflicts, less extreme maneuvers)."* *(2) "Results indicated a tendency to choose vertical over lateral maneuvers, a tendency which was amplified with the coplanar display."* *(3) "Vertical maneuvers by the intruder produced an added source of workload."*	
Limitations/Assumptions: Limitation: Experiments included only one or two intruder aircraft; results do not incorporate traffic densities expected for future Free Flight scenarios. Limitation: The coplanar display requires the pilot to scan between the two planes of data and to mentally reconstruct the three dimensional space; however, there was no evidence observed of increased latencies in evaluating conflicts. As stated by the authors: "*The absence of evidence for planar integration costs for the coplanar display might have been due to the relatively small number of aircraft present in the simulation. Had more aircraft been displayed, the costs which were not found in the present study might have emerged; this is a condition (i.e., a greater number of aircraft) which should be examined in future experiments*." Assumption: Workload is measured using the NASA-TLX workload rating scale.	

Table 25. Synopsis for Research of Wickens, Miller, and Tham.

[H] [WMT96]	Wickens, Miller, and Tham "The Implications of Data-Link for Representing Pilot Request Information on 2D and 3D Air Traffic Control Displays"
Key Words: Human Factor, Data Link, Communications, Gate-to-Gate, CD&R, Flight Plan Changes	
Relevance: FD, ATM; CE 0, CE 5; RI 4, RI 5, RI 6, RI 11, RI 12	**Approach**: Man-in-the-loop Computer Simulation, 17 Pilots; 6 Air Traffic Controllers
Main Contributions: ATM – FD communications scenarios were evaluated in simulation with the results: (1) *"The requests for joint changes in altitude and heading took the longest to evaluate, while those for a single change (only two possible choices, climb or descend) were responded to most rapidly."* (2) *"Overall performance was best with the auditory-verbal request mode*." (3) *"The results suggest that many aspects of the current voice channel request remain quite adequate*." (4) *"The 3D display was particularly poor in supporting complex requests*." Mode 1: Verbal mode of communication Mode 2: Print mode of communication, displayed at the bottom of the display. Mode 3: Spatial mode of communication (2D and 3D) emanating in the requested direction from the requesting aircraft.	
Limitations/Assumptions: Limitation: "*Participants did not enjoy the benefits of flight strips."* Limitation: "*nearly 75% of the participants were not licensed controllers."*	

Table 26. Synopsis for Research of Wickens and Morphew.

<table>
<tr><td>[H] [WM97]</td><td colspan="2">Wickens and Morphew
Predictive Features of a Cockpit Traffic Display: A Workload Assessment</td></tr>
<tr><td colspan="3">**Key Words**: Free Flight, Displays, CDTI, Pilot, Experiments, Perspective vs Co-Planar</td></tr>
<tr><td colspan="2">**Relevance:** FD; CE 5; RI 1, RI 5, RI 6, RI 11</td><td>**Approach**: Man-in-the-loop Simulation, 18 Pilots; NASA TLX Scale for Workload</td></tr>
<tr><td colspan="3">**Main Contributions**: Free Flight scenarios were evaluated in simulation with the results:

(1) Adding intruder prediction as well as point of closest approach threat vector "*improved performance (safety) as assessed by predicted and actual loss of separation (i.e., penetration of the protected zone). Both enhancements also reduced workload, as assessed by the NASA TLX scale*."

(2) "*Our efforts to make perceptually visible, quantities that would otherwise need to be cognitively derived, reduced the workload demands and simultaneously improved performance, a key goal of cognitive engineering and its closely associated field of ecological interface design*."

Display 1: Ownship prediction but no prediction for intruder
Display 2: Ownship prediction and intruder prediction
Display 3: Ownship prediction, intruder prediction, and point of closest approach threat vector</td></tr>
<tr><td colspan="3">**Limitations/Assumptions**:
Limitation: In all scenarios, only one intruder aircraft was present; the effect of moderate or high density Free Flight environments was not considered in this research.

Assumption: Point of closest approach determined by assuming a fixed current heading and vertical velocity for both ownship and intruder.

Assumption: Pilots were allowed to use speed, heading, or altitude control to avoid conflicts.</td></tr>
</table>

Table 27. Synopsis for Research of Gempler and Wickins.

<table>
<tr><td colspan="2">[H] [GW98] Gempler and Wickens
Display of Predictor Reliability on a Cockpit Display of Traffic Information</td></tr>
<tr><td colspan="2">**Key Words**: Free Flight, CD&R, CDTI, Man-in-the-Loop Simulator Experiments, Pilots</td></tr>
<tr><td>**Relevance:** FD; CE 3, CE 5, RI 1, RI 5, RI 6, RI 11</td><td>**Approach**: Man-in-the-loop Simulation, 20 Pilots; ANOVA Analysis</td></tr>
<tr><td colspan="2">**Main Contributions**: Free Flight scenarios were evaluated in simulation.
(1) *“Several dependent variables revealed that intruder descending trials were the most difficult.”*
(2) *“Pilots can still become over-reliant on useful automation tools in general, regardless of the tool’s reliability.”*</td></tr>
<tr><td colspan="2">**Limitations/Assumptions**:
Limitation: As stated by the authors: “*This particular attempt to better calibrate trust in the automation tools was unsuccessful, though other methods of displaying reliability may be more effective in the CDTI*.”
Limitation: The result that “*intruder descending trials were the most difficult*” is inconsistent with previous work of Wickens and Morphew yet consistent with the work of Merwin and Wickens; thus, there is a need to better explain the research topic.
Limitation: As stated by the authors: “Ideally, *a more appropriate display of reliability that will facilitate pilots’ trust calibration will needs to be found to make the CDTI predictor more useful in real world application like free-flight, knowing that the predictor cannot be perfectly reliable*.”
Assumption: A wedge shaped predictor was used that showed an area of 95% confidence for the intruder aircraft’s future position.</td></tr>
</table>

Table 28. Synopsis for Research of Scanlon.

<table>
<tr><td>H [Sc94]</td><td colspan="2">Scanlon
“Cockpit Graphical Weather Information Shown to Enhance Efficiency, Safety, and Situation Awareness”</td></tr>
<tr><td colspan="3">Key Words: CWIN, Display, Weather, Reroute Decisions, En Route, Simulator Flight Tests</td></tr>
<tr><td colspan="2">Relevance: FD; CE 7, CE 9, RI 1, RI 6, RI 11</td><td>Approach: Man-in-the-loop Simulation, 14 Crews; Questionnaire</td></tr>
<tr><td colspan="3">Main Contributions: Weather reroute scenarios were evaluated in simulation with main results:
(1) “All of the test pilots liked the CWIN system.”
(2) “The test crews cleared the thunderstorm cells by three times the distance when they used CWIN as compared to without CWIN.”
(3) “Enroute distances and times flown to avoid adverse weather was reduced 5% when the CWIN system was available for use by the flight crews.”
(4) “Pilot ratings on the post-test questionnaire resulted in the CWIN system being rated as ‘much better for situation awareness’ than the current system of obtaining weather information.”
<u>Scenario 1</u>: No use of CWIN.
<u>Scenario 2</u>: CWIN used..</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Assumption</u>: Basic inflight weather information made available to all test scenarios included textual information on a dispatch release, voice information from ATC and dispatch, textual information obtained over the simulated ACARS data link, and airborne radar depiction..</td></tr>
</table>

Table 29. Synopsis for Research of Prevot, Palmer, and Crane.

[M] [PPC97]	Prevot, Palmer, and Crane "Flight Crew Support for Automated Negotiation of Descent and Arrival Clearances"
Key Words: Data Exchange, FMS, Terminal Area, Workload, Simulation, Human-Centered Automation	
Relevance: FD; CE 8; RI 6, RI 10, RI 11	**Approach**: Man-in-the-loop Simulation, 8 Crews
Main Contributions: Free Flight scenarios were evaluated in simulation. (1) It was concluded that the tested interface *"is unsuitable for high workload flight situations"* (2) *"Flight crews performed the required actions in different orders, because no clear procedures were defined and the pilots had only very little training in dealing with FANS data link."*	
Limitations/Assumptions: <u>Limitation</u>: According to the authors: "*there is currently no empirical support that the proposed data exchange philosophy or the flight deck interface fulfill the relevant requirements and contribute to the overall goal of increasing safety and airspace capacity.*" <u>Assumption</u>: In accordance with human-centered automation guidelines, "*Pilots must remain in command of their flights; Controllers must remain in command of air traffic.*"	

Table 30. Synopsis for Research of Lee, Sanford, and Slattery.

<table>
<tr><td>H [LSS97]</td><td>Lee, Sanford, and Slattery
“The Human Factors of FMS Usage in the Terminal Area”</td></tr>
<tr><td colspan="2">Key Words: Data Exchange, CTAS, Terminal Area, Workload, Full Motion Simulator Experiments</td></tr>
<tr><td>Relevance: FD; CE 8, RI 1, RI 6, RI 10, RI 11</td><td>Approach: Full Motion Simulation, 10 2-person commercial airline crews; ANOVA Analysis; Questionnaire</td></tr>
<tr><td colspan="2">Main Contributions: Free Flight scenarios were evaluated in simulation.
(1) “The amount of time the pilots spent discussing the flight plan was significantly increased in the FMS condition over the other two flight conditions.”
(2) Pilots “perceived that the use of the FMS required too much head-down time, and that it caused both crewmembers to become involve in referencing and programming the FMS regardless of flight condition.”
(3) “In the arrival phase, FMS usage was reported to increase workload.”
<u>Flight Condition 1</u>: Manual Flight
<u>Flight Condition 2</u>: Autopilot
<u>Flight Condition 3</u>: Autopilot coupled with FMS</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: Only one type of aircraft and one type of FMS system was used for all experiments.
<u>Limitation</u>: The FMS was not originally designed to be used in the terminal area.</td></tr>
</table>

Table 31. Synopsis for Research of Pritchett and Yankosky.

[H] [PY00]	Pritchett and Yankosky " Pilot Performance at New ATM Operations: Maintaining In-Trail Separation and Arrival Sequencing"
Key Words: In-Trail Following, Simulation, Terminal Area, CD&R, Roles and Responsibilities	
Relevance: FD; CE 11, CE 12; RI 1, RI 5, RI 6, RI 11	**Approach**: Man-in-the-loop Simulation, 12 Pilots; ANOVA Analysis
Main Contributions: Scenarios were evaluated in simulation with the following results: (1) *"11 out of 12 pilots felt that in-trail spacing was feasible with the displays and procedures tested."* (2) *"Pilots also voiced strong opinions about a continued, active role for the controller."* (3) *"Pilots were found to refer to STAR charts more frequently when the charts had more information, and when the CDTI provided less."* Display 1: Baseline Aircraft Symbol Display 2: Aircraft Symbol with Speed Display 3: Aircraft Symbol with Autopilot Target Speed and Altitude	
Limitations/Assumptions: Assumption: Pilots followed the procedure of the Standard Arrival Route (STAR) to the airport, which included a merging path. The STAR defined procedural knowledge for the experiment.	

Table 32. Synopsis for Research of Cieplak, Hahn, and Olmos.

<table>
<tr><td colspan="2">[M][CHO00] Cieplak, Hahn, and Olmos
“ Safe Flight 21: The 1999 Operational Evaluation of ADS-B Applications”</td></tr>
<tr><td colspan="2">Key Words: Human Factors, ADS-B, ATC, Workload, Pilot Performance, Operational Evaluation</td></tr>
<tr><td>Relevance: FD; ATM; CE 0, CE 5; RI 1, RI 5, RI 6, RI 11</td><td>Approach: Operational Evaluation, 24 Aircraft; 4 Air Traffic Controllers, Questionnaires, Likert</td></tr>
<tr><td colspan="2">Main Contributions: Scenarios were evaluated in an operational evaluation with the following results:
(1) “Flight crews reported the present CDTI implementation to be effective as an aid to visual acquisition, either with our without an ATC traffic call, and that maintaining awareness of multiple traffic targets was less difficult with the CDTI.”
(2) “Display clutter was reported to be manageable during airborne operations.”
(3) “the CDTI improved the efficiency of the visual acquisition task, and they found the workload associated with the use of the CDTI acceptable.”
(4) “The mean approach times with and without the CDTI show a 15% reduction with the CDTI.”
(5) With respect to ATC communications, “a statistically significant increase in the number of transmissions when aircraft were using the CDTI was found.”</td></tr>
<tr><td colspan="2">Limitations/Assumptions:
<u>Limitation</u>: “Crews identified display integration, clutter, and heads down time as issues that need to be addressed in future CDTI implementations.”</td></tr>
</table>

Table 33. Synopsis for Research of Wyndemere, Inc.

<table>
<tr><td>[H] [An96]</td><td colspan="2">Anonymous (Wyndemere, Inc.)
An Evaluation of Air Traffic Control Complexity</td></tr>
<tr><td colspan="3">Key Words: Free Flight, Airspace Complexity, Dynamic Density, ATC, CD&R, Workload</td></tr>
<tr><td colspan="2">Relevance: ATM; CE 5; RI 2, RI 5, RI 9, RI 11</td><td>Approach: Man-in-the-loop Simulation, 10 Air Traffic Controllers; ANOVA Analysis</td></tr>
<tr><td colspan="3">Main Contributions: Free Flight scenarios were evaluated in simulation with the following results:
(1) As shown in Table 34, the highest ranking factors in complexity are: 1. Level of knowledge of intent, 2. Density of aircraft, and 3. Number of crossing altitude profiles.
(2) “The level of importance that controllers placed on timely aircraft intent information should be reflected in the design of a Free Flight system.”
<u>Condition 1</u>: Current Procedures
<u>Condition 2</u>: Half Free Flight Procedures – aircraft allowed to vary within a given bandwidth about their nominal trajectories, providing flexibility to aircraft and intent for controllers
<u>Condition 3</u>: Full Free Flight Procedures – aircraft allowed to change heading and/or speed as desired.</td></tr>
<tr><td colspan="3">Limitations/Assumptions:
<u>Limitation</u>: Controllers commented that one aspect of their job was not modeled in the simulation, namely, the coordination of activity with neighboring sectors or facilities and hand-offs.
<u>Limitation</u>: No weather was included in the simulation experiments.
<u>Assumption</u>: Complexity of the ATC traffic situation was analyzed for all sectors in the Denver ARTCC airspace. Results are assumed to be applicable to other NAS airspaces.</td></tr>
</table>

Table 34. Factors contributing to airspace complexity [An96].

Complexity Factor	Ranking*
Level of Knowledge of Intent	7.9
Density of Aircraft	7.2
Number of Crossing Altitude Profiles	7.2
Proximity of Neighboring Aircraft	6.7
Coordination level of effort	6.7
Points of Closest Approach Distribution	6.5
Number of Aircraft Climbing and Descending	6.4
Separation Requirements	6.3
Proximity of Potential Conflicts to Sector Boundary	6.0
Angle of Convergence in a Conflict Situation	6.0
Complexity of the Airspace Structure	5.2
Variance in Directions of Flight of all Aircraft	5.1
Mixture in Performance of all Aircraft	5.1
Number of Facilities servicing a given Airspace Region	5.0
Variance in Aircraft Speed for all Aircraft	4.3
Presence and Operation of SUA in the Airspace	3.9
Weather Effects on Aircraft Density	3.2

** Ranking on 0 – 10 scale with 0 for low importance and 10 for high importance.*

Table 35. Synopsis for Research of Laudeman, Shelden, Branstrom, and Brasil.

[H] [LSBB98]	Laudeman, Shelden, Branstrom, and Brasil *Dynamic Density: An Air Traffic Management Metric*
Key Words: Dynamic Density, Traffic Complexity, Human Factors, ATM, Workload	
Relevance: ATM; CE 5; RI 2, RI 5, RI 9, RI 11	**Approach**: Man-in-the-loop Simulation, 5 Air Traffic Controllers; ANOVA Analysis
Main Contributions: Free Flight scenarios were evaluated in simulation with the following results: (1) As shown in Table 36, the highest ranking factors in complexity are: 1. Heading Changes, 2. Predicted conflicts, and 3. Miss distance. (2) When compared with operational data, "*Dynamic density correlated more highly with observed controller activity than did traffic density for 17 of the 18 data collection periods*."	
Limitations/Assumptions: Assumption: Complexity of the ATC traffic situation was analyzed as a linear combination of complexity factors; no non-linear effects were considered..	

Table 36. Factors contributing to traffic complexity [LSBB98].

Complexity Factor	Ranking*
Heading Changes	2.17
Conflict Predicted from 25 nmi to 40 nmi	1.85
Conflict Predicted from 40 nmi to 70 nmi	1.85
Minimum Distance from 5 nmi to 10 nmi	1.18
Minimum Distance from 0 nmi to 5 nmi	1.02
Altitude Changes	0.88
Traffic Density	0.79

* *A multiple regression weighting analysis with lower weights indicating less significance.*

2.2 Analysis

Analysis is focused on the relevance of the literature to the ATM-AOC-FD triad, the Concept Elements (CEs), and the Research Issues (RIs) presented in Chapter 1. Those CEs and RIs that do not have supporting research will be discussed later, as they identify areas for suggested future research. Results are presented in several tables. Figure 4 classifies literature by relevance to each triad element, Table 37 classifies by CEs, and Table 38 classifies by RIs.

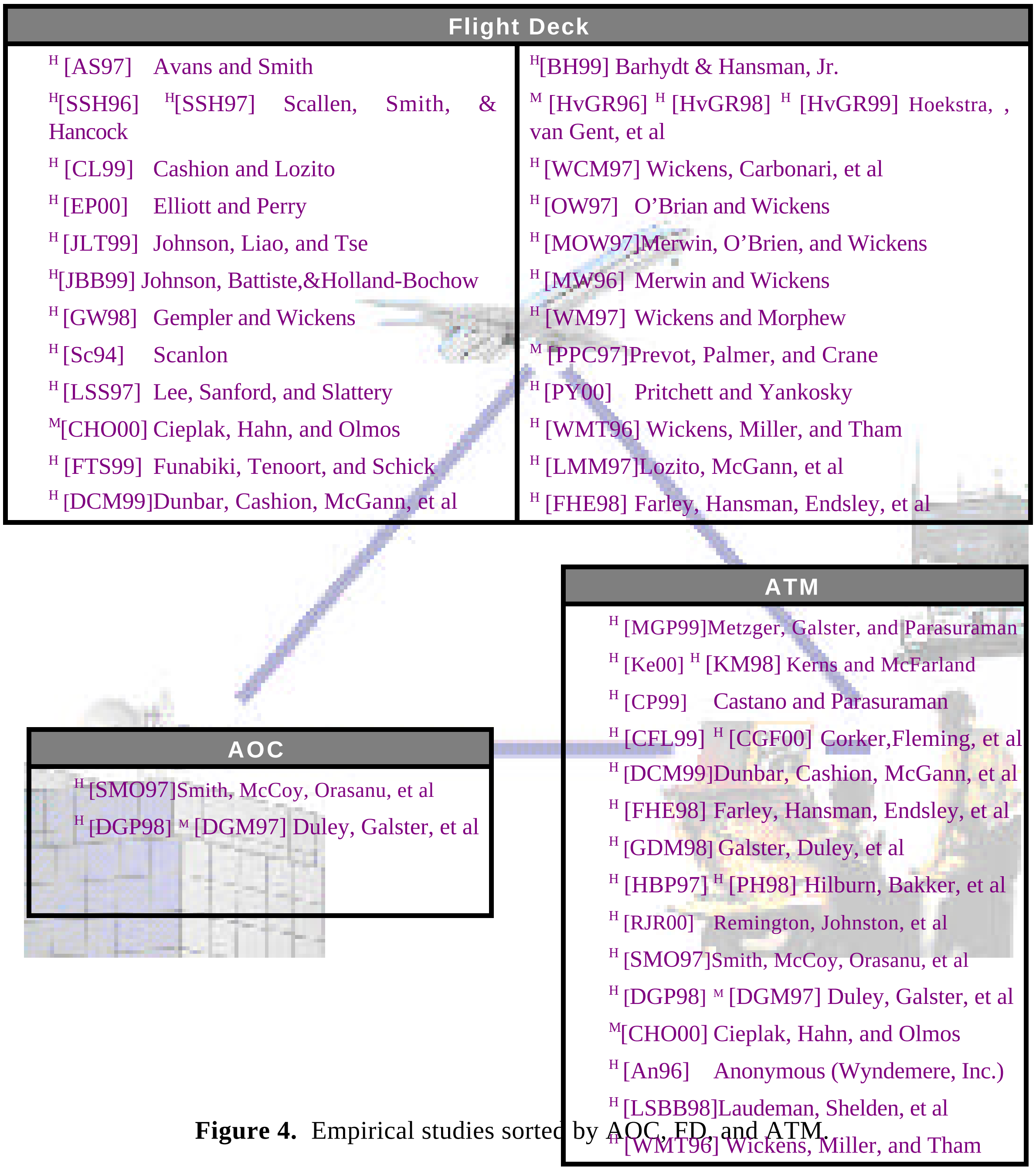

Figure 4. Empirical studies sorted by AOC, FD, and ATM.

Table 37. The DAG-TM Concept Elements augmented with Supporting Research Literature.

CE	Flight Phase	Title/Supporting Research Literature
0	Gate-to-Gate:	Information Access/Exchange for Enhanced Decision Support
		[M][CHO00] Cieplak, Hahn, and Olmos [H] [SMO97] Smith, McCoy, Orasanu, et al [H] [DGP99] [M] [DGP98] [M] [DGM97] Duley, Galster, et al [H] [WMT96] Wickens, Miller, and Tham
1	Pre-Flight Planning:	NAS-Constraint Considerations for Schedule/Flight Optimization
		None
2	Surface Departure:	Intelligent Routing for Efficient Pushback Times and Taxi
		None
3	Terminal Departure:	Free Maneuvering for User-Preferred Departures
		[H] [BH99] Barhydt and Hansman, Jr. [H] [MW96] Merwin and Wickens [H] [GW98] Gempler and Wickens
4	Terminal Departure:	Trajectory Negotiation for User-Preferred Departures
		None
5	En route: *(Departure, Cruise, Arrival)*	Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
		[H] [An96] Anonymous (Wyndemere, Inc.) [H] [AS97] Avans and Smith [H] [BH99] Barhydt and Hansman, Jr. [H] [CL99] Cashion and Lozito [H] [CP99] Castano and Parasuraman [M][CHO00] Cieplak, Hahn, and Olmos [H] [CFL99] [H] [CGF00] Corker, Fleming, et al [H] [DGP99] [M] [DGP98][M] [DGM97] Duley, Galster, et al [H] [DCM99] Dunbar, Cashion, McGann, et al [H] [FTS99] Funabiki, Tenoort, and Schick [H] [GDM98] Galster, Duley, et al [H] [GW98] Gempler and Wickens [H] [HBP97] [H] [PH98] Hilburn, Bakker, et al [M] [HvGR96], [H] [HvGR98] Hoekstra, , van Gent, et al [H] [JBB99] Johnson, Battiste, and Holland-Bochow [H] [JLT99] Johnson, Liao, and Tse [H] [Ke00] [H] [KM98] Kerns and McFarland [H] [LSBB98]Laudeman, Shelden, et al [H] [LMM97] Lozito, McGann, Mackintosh, and Cashion [H] [MOW97] Merwin, O'Brien, and Wickens [H] [MW96] Merwin and Wickens [H] [MGP99] Metzger, Galster, and Parasuraman [H] [OW97] O'Brian and Wickens [H] [RJR00] Remington, Johnston, et al

CE	Flight Phase	Title/Supporting Research Literature
		H [SSH96] H [SSH97] Scallen, Smith, and Hancock H [SMO97]Smith, McCoy, Orasanu, et al H [WCM97] Wickens, Carbonari, Merwin, et al H [WMT96] Wickens, Miller, and Tham H [WM97] Wickens and Morphew
6	En route: *(Departure, Cruise, Arrival)*	Trajectory Negotiation for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance
		H [DGP99] M [DGP98]M [DGM97] Duley, Galster, et al H [DCM99] Dunbar, Cashion, McGann, et al H [FHE98] Farley, Hansman, Endsley, et al H [FTS99] Funabiki, Tenoort, and Schick H [SMO97]Smith, McCoy, Orasanu, et al
7	En route: *(Departure, Cruise, Arrival)*	Collaboration for Mitigating Local TFM Constraints due to Weather, SUA and Complexity
		H [DGP99] M [DGP98]M [DGM97] Duley, Galster, et al H [FHE98] Farley, Hansman, Endsley, et al H [SMO97]Smith, McCoy, Orasanu, et al H [Sc94] Scanlon
8	En route / Terminal Arrival:	Collaboration for User-Preferred Arrival Metering
		H [DGP99] M [DGP98]M [DGM97] Duley, Galster, et al H [SMO97]Smith, McCoy, Orasanu, et al H [LSS97] Lee, Sanford, and Slattery M [PPC97]Prevot, Palmer, and Crane
9	Terminal Arrival:	Free Maneuvering for Weather Avoidance
		H [Sc94] Scanlon H [WCM97] Wickens, Carbonari, Merwin, et al H [OW97] O'Brian and Wickens H [MOW97] Merwin, O'Brien, and Wickens
10	Terminal Arrival:	Trajectory Negotiation for Weather Avoidance
		None
11	Terminal Arrival:	Self Spacing for Merging and In-Trail Separation H [PY00] Pritchett and Yankosky H [EP00] Elliott and Perry
12	Terminal Arrival:	Trajectory Exchange for Merging and In-Trail Separation
		H [PY00] Pritchett and Yankosky H [EP00] Elliott and Perry
13	Terminal Approach:	Airborne CD&R for Closely Spaced Approaches
		H [EP00] Elliott and Perry
14	Surface Arrival:	Intelligent Routing for Efficient Active-Runway Crossings and Taxi
		None

Table 38. The Research Issues augmented with Supporting Research Literature.

RI	Research Issue	Title/Supporting Research Literature
1	What will be the role and responsibility of the pilot in Free Flight?	
		H [AS97] Avans and Smith H [BH99] Barhydt and Hansman, Jr. H [CL99] Cashion and Lozito M [CHO00] Cieplak, Hahn, and Olmos H [DCM99] Dunbar, Cashion, McGann, et al H [EP00] Elliott and Perry H [FHE98] Farley, Hansman, Endsley, et al H [FTS99] Funabiki, Tenoort, and Schick H [GW98] Gempler and Wickens M [HvGR96], H [HvGR98] Hoekstra, , van Gent, et al H [JLT99] Johnson, Liao, and Tse H [JBB99] Johnson, Battiste, and Holland-Bochow H [LSS97] Lee, Sanford, and Slattery H [LMM97] Lozito, McGann, Mackintosh, and Cashion H [MOW97] Merwin, O'Brien, and Wickens H [MW96] Merwin and Wickens H [OW97] O'Brian and Wickens H [PY00] Pritchett and Yankosky H [SSH96] H [SSH97] Scallen, Smith, and Hancock H [Sc94] Scanlon H [WCM97] Wickens, Carbonari, Merwin, et al H [WM97] Wickens and Morphew
2	What will be the role and responsibility of the air traffic controller or ATSP in Free Flight?	
		H [An96] Anonymous (Wyndemere, Inc.) H [CP99] Castano and Parasuraman H [CFL99] H [CGF00] Corker, Fleming, et al H [DGP99] M [DGP98] M [DGM97] Duley, Galster, et al H [DCM99] Dunbar, Cashion, McGann, et al H [FHE98] Farley, Hansman, Endsley, et al H [GDM98] Galster, Duley, et al H [HBP97] H [PH98] Hilburn, Bakker, et al H [Ke00] H [KM98] Kerns and McFarland H [LSBB98]Laudeman, Shelden, et al H [MGP99] Metzger, Galster, and Parasuraman H [RJR00] Remington, Johnston, et al H [SMO97]Smith, McCoy, Orasanu, et al
3	What will be the role and responsibility of the AOC dispatcher in Free Flight?	
		H [DGP99] M [DGP98] M [DGM97] Duley, Galster, et al H [SMO97]Smith, McCoy, Orasanu, et al
4	How can information distribution and collaborative decision making enable user preferences in Free Flight?	
		H [DGP99] M [DGP98] M [DGM97] Duley, Galster, et al

RI	Research Issue	Title/Supporting Research Literature
		H [FHE98] Farley, Hansman, Endsley, et al H [SMO97]Smith, McCoy, Orasanu, et al H [WMT96] Wickens, Miller, and Tham
5	How will pilots and ATSP share the responsibility for separation assurance in a Free Flight environment?	
		H [An96] Anonymous (Wyndemere, Inc.) H [AS97] Avans and Smith H [BH99] Barhydt and Hansman, Jr. H [CL99] Cashion and Lozito H [CP99] Castano and Parasuraman M[CHO00] Cieplak, Hahn, and Olmos H [CFL99] H [CGF00] Corker, Fleming, et al H [DCM99] Dunbar, Cashion, McGann, et al H [EP00] Elliott and Perry H [FHE98] Farley, Hansman, Endsley, et al H [FTS99] Funabiki, Tenoort, and Schick H [GDM98] Galster, Duley, et al H [GW98] Gempler and Wickens H [HBP97] H [PH98] Hilburn, Bakker, et al M [HvGR96], H [HvGR98] Hoekstra, , van Gent, et al H [JLT99] Johnson, Liao, and Tse H [JBB99] Johnson, Battiste, and Holland-Bochow H [Ke00] H [KM98] Kerns and McFarland H [LSBB98]Laudeman, Shelden, et al H [LMM97] Lozito, McGann, Mackintosh, and Cashion H [MOW97] Merwin, O'Brien, and Wickens H [MW96] Merwin and Wickens H [MGP99] Metzger, Galster, and Parasuraman H [OW97] O'Brian and Wickens H [PY00] Pritchett and Yankosky H [RJR00] Remington, Johnston, et al H [SSH96] H [SSH97] Scallen, Smith, and Hancock H [WCM97] Wickens, Carbonari, Merwin, et al H [WMT96] Wickens, Miller, and Tham H [WM97] Wickens and Morphew
6	What new CDTIs and other cockpit DSTs are needed for pilots to effectively participate in Free Flight?	
		H [AS97] Avans and Smith H [BH99] Barhydt and Hansman, Jr. H [CL99] Cashion and Lozito M[CHO00] Cieplak, Hahn, and Olmos H [EP00] Elliott and Perry H [FHE98] Farley, Hansman, Endsley, et al H [FTS99] Funabiki, Tenoort, and Schick H [GW98] Gempler and Wickens

RI	Research Issue	Title/Supporting Research Literature
		M [HvGR96], H [HvGR98] Hoekstra, , van Gent, et al H [JLT99] Johnson, Liao, and Tse H [JBB99] Johnson, Battiste, and Holland-Bochow H [LSS97] Lee, Sanford, and Slattery H [LMM97] Lozito, McGann, Mackintosh, and Cashion H [MOW97] Merwin, O'Brien, and Wickens H [MW96] Merwin and Wickens H [OW97] O'Brian and Wickens M [PPC97]Prevot, Palmer, and Crane H [PY00] Pritchett and Yankosky H [SSH96] H [SSH97] Scallen, Smith, and Hancock H [Sc94] Scanlon H [WCM97] Wickens, Carbonari, Merwin, et al H [WMT96] Wickens, Miller, and Tham H [WM97] Wickens and Morphew
7	What new DSTs will enable greater user preferences of the AOC dispatcher in Free Flight?	
		None
8	What new DSTs will enable air traffic service providers in Free Flight?	
		H [CP99] Castano and Parasuraman H [CFL99] H [CGF00] Corker, Fleming, et al H [FHE98] Farley, Hansman, Endsley, et al H [Ke00] H [KM98] Kerns and McFarland H [MGP99] Metzger, Galster, and Parasuraman H [RJR00] Remington, Johnston, et al
9	How will airspace be dynamically managed to control workload and safety in Free Flight?	
		H [An96] Anonymous (Wyndemere, Inc.) H [LSBB98]Laudeman, Shelden, et al
10	Do current DSTs that will be used in the initial Free Flight environment abide by human-centered-automation guidelines?	
		H [LSS97] Lee, Sanford, and Slattery M [PPC97]Prevot, Palmer, and Crane
11	What level of automation is required or desired in the design of new interfaces for pilots or controllers?	
		H [An96] Anonymous (Wyndemere, Inc.) H [AS97] Avans and Smith H [BH99] Barhydt and Hansman, Jr. H [CL99] Cashion and Lozito H [CP99] Castano and Parasuraman M[CHO00] Cieplak, Hahn, and Olmos H [CFL99] H [CGF00] Corker, Fleming, et al H [EP00] Elliott and Perry H [FHE98] Farley, Hansman, Endsley, et al H [FTS99] Funabiki, Tenoort, and Schick

RI	Research Issue	Title/Supporting Research Literature
		[H] [GDM98] Galster, Duley, et al [H] [GW98] Gempler and Wickens [H] [HBP97] [H] [PH98] Hilburn, Bakker, et al [M] [HvGR96], [H] [HvGR98] Hoekstra, , van Gent, et al [H] [JLT99] Johnson, Liao, and Tse [H] [JBB99] Johnson, Battiste, and Holland-Bochow [H] [Ke00] [H] [KM98] Kerns and McFarland [H] [LSBB98]Laudeman, Shelden, et al [H] [LSS97] Lee, Sanford, and Slattery [H] [LMM97] Lozito, McGann, Mackintosh, and Cashion [H] [MOW97] Merwin, O'Brien, and Wickens [H] [MW96] Merwin and Wickens [H] [MGP99] Metzger, Galster, and Parasuraman [H] [OW97] O'Brian and Wickens [M] [PPC97]Prevot, Palmer, and Crane [H] [PY00] Pritchett and Yankosky [H] [RJR00] Remington, Johnston, et al [H] [SSH96] [H] [SSH97] Scallen, Smith, and Hancock [H] [Sc94] Scanlon [H] [WCM97] Wickens, Carbonari, Merwin, et al [H] [WMT96] Wickens, Miller, and Tham [H] [WM97] Wickens and Morphew
12	How will Datalink change the nature and efficiency of communication?	
		[H] [DGP99] [M] [DGP98] [M] [DGM97] Duley, Galster, et al [H] [EP00] Elliott and Perry [H] [FHE98] Farley, Hansman, Endsley, et al [H] [SMO97]Smith, McCoy, Orasanu, et al [H] [WMT96] Wickens, Miller, and Tham

2.3 Discussion

Based on the analysis, there are a few general results that emerge:

- Most of the empirical studies have been for the Flight Deck, a good amount for ATM, and finally, very few studies have been performed for the AOC.
- A majority of the empirical studies that have been performed are related to CE 5, more than any other CE.
- No literature based on empirical studies was located within this literature search to support CEs 1, 2, 4, 10, 14.
- There are a lot of studies that support RIs 1, 2, 5, 6, 11.
- No literature based on empirical studies was located within this literature search to support RI 7.

In addition to these general findings, we next present more detailed statements derived from the survey synopses.

2.3.1 Free Flight Empirical Studies Related to the Flight Deck

Very many empirical results related to the flight deck were revealed in the literature survey:

- Crews take significantly longer to detect conflicts and have increased workload in high density conditions compared to low density conditions
- Crews more often detected a conflict prior to an alert than after an alert
- It is more common for the Free Flight pilots to contact the intruder aircraft than not to contact them; communication is usually prior to an alert
- Many factors influence maneuver choice (including type of conflict being overtake, merging, or head-on); some empirical studies conclude that pilots chose to maneuver vertically more than laterally, while others conclude that lateral maneuvers were chosen more often than vertical maneuvers
- Pilots have more operational errors when being overtaken by another aircraft than with crossing or converging conflicts
- Vertical maneuvers by the intruder produce an added source of workload
- While additional intent and other information (e.g., 3D flight plans) aids pilot performance in Free Flight, many studies identify a problem with clutter in the display as traffic density increases
- Greater degrees of intent are preferred by pilots even with associated clutter problems
- Many pilots feel that in-trail spacing is feasible with the assistance of CDTIs
- In parallel approach situations, the distance aircraft close on each other before they break out of the approach is not affected by flight control mode or runway separation distance
- The estimation of the speed of another aircraft and the time to closest approach proves to be a challenge to pilots and produces high levels of cognitive effort
- Efforts to make perceptually visible quantities that would otherwise need to be cognitively derived (point of closest approach), reduced workload demands and simultaneously improved performance
- At terminal arrivals, FMS usage tends to increase workload, and requires additional head-down time
- A CDTI improves the efficiency of the visual acquisition task, and the workload associated with the use of a CDTI is acceptable
- Color-coding within traffic symbology and flight plans is liked by pilots
- Pilot effort increases when the color of an aircraft in the CDTI changes to indicate closer proximity
- A color CDTI allows pilots to execute maneuvers earlier than pilots without color CDTI
- Brightness appears to have no effect on attracting a pilot’s initial attention to a conflict
- A coplanar display (plan view and profile) has an advantage over a 3D perspective display, particularly when a vertical intruder exists
- A tendency to choose vertical over lateral maneuvers is amplified with a coplanar display

- Measures of flight safety favor the coplanar display over a 3D perspective display in terms of actual traffic conflicts, predicted traffic conflicts, and weather conflicts
- The most pronounced negative effect of a 3D perspective display is the effect of 3D ambiguity
- Many aspects of the current pilot-controller voice channel remain quite adequate for Free Flight
- When CDTIs are used in Free Flight, a statistically significant increase in the number of communication transmissions occurs
- With a datalink enabled, pilots and controllers make more voluntary suggestions to one another for specific route adjustments
- Pilots have biases to attend to different display locations in a visual search task
- Pilots perform weather avoidance better with a CDTI that includes weather information
- Pilots are best served by displays in which traffic and weather are overlaid within the same panel, and when the traffic and weather information is shared with the ATSP
- Predictive elements improve safety (reduce actual and predicted conflicts) and reduce workload, although the different predictive elements affected workload in different ways
- Greater safety benefits occur using a CDTI with TCAS included instead of TCAS alone
- Providing intent information directly on a display or incorporating it into a conflict probe both lead to fewer separation violations and earlier maneuvers compared to the basic TCAS display
- More than one study supports an airborne separation assurance concept for Free Flight
- Pilots voice strong opinions about a continued, active role for the controller in Free Flight

2.3.2 Free Flight Empirical Studies Related to the AOC

There were not a lot of empirical research studies with respect to the AOC found in this literature survey. However, the following results indicate the latest findings for human factors issues for the AOC in Free Flight:

- Collaborative Decision Making (CDM) and cooperative problem solving are the primary research areas studied with respect to the AOC and Free Flight
- In CDM, it is necessary to have a shared understanding of goals, problems, constraints, and solutions
- There exists a distribution of responsibilities to a number of different individuals at both the AOC and ATSP
- Feedback and process control loops must be modeled as a part of the CDM problem

2.3.3 Free Flight Empirical Studies Related to the ATSP

Many findings from empirical studies related to Free Flight provide guidance for ATSP related research:

- Both traffic load and conflict geometry (obtuse angle vs. right angle vs. acute angle) have effects on conflict detection times for air traffic controllers

- The level of intent information affects controller operational errors and conflict prediction time
- The degrading influence of low intent is particularly severe under high traffic densities
- Controllers feel strongly that aircraft intent should always be available to the controller, and prefer to know about intent prior to maneuver initiation
- Controllers find that Free Flight workload is often lower than they originally anticipated
- Greater amounts of traffic density increase visual and mental workload
- In high density airspace, controllers have difficulty both in detecting conflicts and in recognizing self-separating events in a timely manner
- A conflict probe reduces workload under high volume Free Flight conditions
- A Free Flight conflict probe for controllers should have a look ahead capability of well over five minutes
- Controllers vary in their presentation preferences, they perform their tasks concurrently rather than sequentially, and their information requirements are task dependent
- Requests for joint changes in altitude and heading take longer to evaluate compared to those for a single change (e.g., altitude or heading)
- Free Flight is likely to bring an increased level of altitude resolution maneuvers in high volume conditions
- Color-coding of altitude reduces conflict detection times
- When CDTIs are used in Free Flight, a statistically significant increase in the number of communication transmissions occurs
- Many aspects of the current pilot-controller voice channel remain quite adequate for Free Flight
- A 3D display is particularly poor in supporting complex Free Flight user requests, but a coplanar tool (plan view augmented with a side view) may be useful in monitoring aircraft self-separation
- With respect to dynamic density and how it affects air traffic controller, there is no one agreed upon definition for dynamic density for neither today's air traffic control system nor for Free Flight
- Dynamic density correlates better than traffic density with respect to observed controller activity
- While the definitions of dynamic density vary, the top factors influencing dynamic density include: intent, density of aircraft, number of crossing altitude profiles, heading changes, predicted conflicts, and miss distance.

2.3.4 Persistent Problems and Limitations with Free Flight Empirical Studies

Finally, there are several re-occurring problems and limitations that are identified with the empirical studies of this literature survey; these include:

- Very many of the CDTI studies assume constant velocity assumptions for the motion of intruder aircraft yet in Free Flight, aircraft are free to maneuver whenever and wherever they choose

- None of the studies implement wind, turbulence, or SUA conditions, and very few of the studies include any presence of weather
- While many studies include the use of a conflict detection and resolution aid, no study includes the use of a weather avoidance aid
- Some of the studies evaluate concepts without including any traffic
- Very little has been studied about the transition between control authority between airborne separation assurance being in effect transitioning to ground-based positive control being in effect
- Except for lessons learned through the NRP, no empirical study has been performed to investigate the evolution between our current positive control system for air traffic control towards a mature Free Flight intervention by exception system
- Very few of the studies include any mention or consideration for mixed equipage among aircraft nor the consideration of multiple user classes involved in conflicts (general aviation, commercial, military, helicopters, and business jet classes)
- There is no indication that any of the studies ever consider imperfect data link and communication transmissions
- There is no indication that any of the studies include any element of adversarial gaming or bias due to competition between commercial airlines, and if this may reduce safety
- There is no indication in any of the literature that there exists a simulation facility that simulates the AOC human-computer interaction analogous to the cockpit simulators and air traffic controller simulators that exist for several studies
- Aside from AOC dispatcher interviews discussing potential Free Flight scenarios, there are no empirical studies that directly compare two concepts under controlled conditions for AOC related Free Flight research issues

3.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

3.1 Summary

This report documents how a survey of Free Flight research issues and concepts was conducted and presents the survey findings. First, a review of four key documents was performed to define Free Flight and DAG-TM concepts. Key words were identified from the definitions and research issues related to these definitions. Next, an e-mail survey was conducted to identify research issues related to Free Flight from researchers and stakeholders. From the e-mail survey, key words were extracted. Then, a process was described for how these key words were used to guide the literature survey. This process incorporates a ranking (high, medium, low) of literature based on relevance, and an approach for reviewing the literature that could be stopped at any time. The highest ranked papers were reviewed and a synopsis was given for each one. Next, the results of the literature search were categorized based on relevance to the ATM/AOC/Flight Deck triad, the DAG-TM Concept Elements (CEs), and the Research Issues (RIs). Analysis of these results identified trends and areas where future research is needed.

3.2 Conclusions

Based on the analysis of this report, there are a few general results that emerge:

- Most of the empirical studies have been for the Flight Deck, a good amount for ATM, and finally, very few studies have been performed for the AOC.
- A majority of the empirical studies that have been performed are related to CE 5, Free Maneuvering for: (a) User-preferred Separation Assurance, and (b) User-preferred Local TFM Conformance, more than any other CE.
- No literature based on empirical studies was located within this literature search to support CEs 1, 2, 4, 10, 14:
    - ◊ CE 1: Pre-Flight Planning: NAS-Constraint Considerations for Schedule/Flight Optimization
    - ◊ CE 2: Surface Departure: Intelligent Routing for Efficient Pushback Times and Taxi
    - ◊ CE 4: Terminal Departure: Trajectory Negotiation for User-Preferred Departures
    - ◊ CE 10: Terminal Arrival: Trajectory Negotiation for Weather Avoidance
    - ◊ CE 14: Surface Arrival: Intelligent Routing for Efficient Active-Runway Crossings and Taxi
- There are a lot of studies that support RIs 1, 2, 5, 6, 11.
    - ◊ RI 1: What will be the role and responsibility of the pilot in Free Flight?
    - ◊ RI 2: What will be the role and responsibility of the ATSP in Free Flight?
    - ◊ RI 5: How will pilots and ATSP share the responsibility for separation assurance in a Free Flight environment?
    - ◊ RI 6: What new CDTIs and other cockpit DSTs are needed for pilots to effectively participate in Free Flight?

◊ RI 11: What level of automation is required or desired in the design of new interfaces for pilots or controllers?

- No literature based on empirical studies was located within this literature search to support RI 7: What new DSTs will enable greater user preferences of the AOC dispatcher in Free Flight?

3.3 Recommendations

Further research is needed to investigate those topics critical to DAG-TM that are not currently being adequately researched:

- The effects of wind, turbulence, SUA, and adverse weather conditions needs to be better explored for Free Flight scenarios, otherwise, CDTIs and DSTs for Free Flight could become “clumsy automation” where they decrease workload in normal operating conditions but potentially increase workload or are inneffective in higher workload or abnormal working conditions
- More work needs to be performed to study the transition between control authority between airborne separation assurance being in effect transitioning to ground-based positive control being in effect
- An empirical study needs to be performed to investigate the evolution between our current positive control system for air traffic control towards a mature Free Flight intervention by exception system
- Further studies are needed that include consideration for mixed equipage among aircraft and the consideration of multiple user classes involved in airspace usage and conflicts (general aviation, commercial, military, helicopters, and business jet classes)
- NASA and/or the FAA needs to sponsor the creation of an AOC simulation facility that includes AOC human-computer interaction analogous to the cockpit simulators and air traffic controller simulators that exist today; after building such a facility, further research is needed to explore the important role of the AOC in Collaborative Decision Making (CDM) for Free Flight and to support RI 7: What new DSTs will enable greater user preferences of the AOC dispatcher in Free Flight?
- Further empirical human factors studies need to be run to support DAG-TM CEs 1, 2, 4, 10, 14:

  ◊ CE 1: Pre-Flight Planning: NAS-Constraint Considerations for Schedule/Flight Optimization

  ◊ CE 2: Surface Departure: Intelligent Routing for Efficient Pushback Times and Taxi

  ◊ CE 4: Terminal Departure: Trajectory Negotiation for User-Preferred Departures

  ◊ CE 10: Terminal Arrival: Trajectory Negotiation for Weather Avoidance

  ◊ CE 14: Surface Arrival: Intelligent Routing for Efficient Active-Runway Crossings and Taxi

Finally, since research results are being established continuously in the literature, this survey can be incrementally built up as new research results are reported.

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APPENDIX A: http://www.faa.gov/freeflight/

Recorded April 3, 2000

What is Free Flight?

Free Flight is an innovative concept designed to enhance the safety and efficiency of the National Airspace System (NAS). The concept moves the NAS from a centralized command-and-control system between pilots and air traffic controllers to a distributed system that allows pilots, whenever practical, to choose their own route and file a flight plan that follows the most efficient and economical route.

Free Flight calls for limiting pilot flexibility in certain situations, such as, to ensure separation at high-traffic airports and in congested airspace, to prevent unauthorized entry into special use airspace, and for any safety reason.

In essence, any activity that removes restrictions represents a move toward Free Flight. From pre-flight planning to destination parking, Free Flight provides the aviation community with enhanced safety and more flexibility.

Free Flight is being developed, tested, and implemented incrementally by the Federal Aviation Administration (FAA) and the aviation community. Safety remains the highest priority throughout the transition to full Free Flight.

Why Free Flight?

The annual air traffic rate is expected to grow by 3 to 5 percent for at least the next 15 years, and the current airspace architecture and management will not be able to efficiently handle this increase. Implementation of Free Flight, which offers benefits in system safety, capacity, and efficiency, is key to advancing aviation by accommodating the nation's growing airspace needs.

What's Required for Free Flight?

Full implementation of Free Flight requires use of current and new ground- and air-based communications, navigation, and surveillance equipment, avionics, and decision support systems (automation). These, coupled with supporting procedures and systems, enable easy and accurate coordination between system users and the FAA's air traffic control facilities.

New and improved technology and supporting procedures are also required to give users and service providers real-time, accurate, and detailed information for improved situation awareness, communications, and coordination. Clear-cut lines of authority and responsibility between pilots and air traffic controllers will continue, with better tools and information to help their decision-making.

Government and industry program funding is a crucial factor for Free Flight implementation. Only with a total aviation community commitment to research, development, and capital investment can Free Flight deliver its wide-ranging benefits.

How Does Free Flight Work?

Central to the Free Flight concept is the principle of maintaining safe airborne separation. This principle is based on two airspace zones, protected and alert, the sizes of which are based on the aircraft's speed, performance characteristics, and communications, navigation, and surveillance equipment. The protected zone, the one closest to the aircraft, can never meet the protected zone of another aircraft. The alert zone extends well beyond the protected zone, and aircraft can maneuver freely until alert zones touch. If alert zones do touch, a controller may provide one or both pilots with course corrections or restrictions to ensure separation. Eventually, most commands will be sent via data link, an integrated network of air, ground, and airborne communications systems. Additionally, onboard computers and Global Positioning System satellites will allow pilots, with the concurrence of controllers, to use airborne traffic displays to choose solutions.

What are the Benefits of Free Flight?

Free Flight is designed to provide the user community with the flexibility to better manage its operations and the capability to benefit from advanced avionics. The requirement for users to receive benefits from the implementation of Free Flight is essential.

By providing for more efficient routes, Free Flight will reduce user operating costs. Free Flight will allow the user's aircraft to reach its destination at the prescribed time. These improvements will result in air quality benefits through reductions in fuel burn.

Free Flight will also enable air traffic controllers to accommodate future air traffic growth through a decision support system at an affordable cost to users. By providing the user with incentives to modernize their equipment, the FAA will move to a modern infrastructure, reducing the FAA operations and maintenance burdens while increasing safety.

Who's Involved with Free Flight?

Free Flight is a joint initiative of the global aviation industry and the FAA. The planning has been done principally through RTCA, Inc., an organization that serves in an advisory capacity to the FAA. In 1994, RTCA formed a government and industry select committee to study Free Flight. The committee's report defined the Free Flight concept and the first steps for its implementation. In 1995, at the request of the FAA Administrator, RTCA formed Task Force 3 to further define the procedures, system architecture, and transition recommendations. This 250-member group included representatives from general and business aviation, the airline industry, pilot and controller unions, industry suppliers, academia, and Government. The group published its recommendations in October 1995.

In 1996, the FAA Administrator confirmed the agency's commitment to Free Flight and a seamless global air traffic management system. The FAA, working with aviation leaders from around the world, developed a Free Flight action plan, responding to the RTCA Task Force recommendations. Also in 1996, a Government/industry Free Flight Steering Committee was formed to establish an implementation strategy and milestones; to periodically review Government and industry progress in meeting implementation commitments; to identify new Free Flight implementation opportunities; and to increase public awareness and understanding of Free Flight. The challenge before the Government/industry group is to implement a plan that is technically feasible, affordable, and operationally sound.

How is Free Flight Coordinated Internationally?

International coordination is being accomplished through the RTCA Government/industry Free Flight Steering Committee which contains international representation, the FAA's membership in the International Civil Aviation Organization (ICAO), and the FAA's close working relationship with Eurocontrol. The phased approach for Free Flight, along with international aviation participation, contributes to building a seamless global airspace system.

When Will Free Flight be Implemented?

Free Flight is already underway, and the plan for full implementation will occur as procedures are modified and technologies become available and are acquired by users and service providers. This incremental approach balances the needs of the aviation community and the expected resources of both the FAA and the users.

Near-term improvements will focus on reducing air traffic restrictions, implementing procedures that increase user flexibility and system capacity, and fielding technologies for the NAS and user systems.

Two current Free Flight programs are the expanded National Route Program (NRP) and the Central Pacific Oceanic Program. The NRP uses procedural changes to allow pilots flying at or above predetermined flight levels to choose their own flight paths. Current estimates indicate that the NRP saves the aviation industry over $40 million annually.

In the airspace over the Central Pacific, advanced satellite voice and data communications are being used to provide faster and more reliable transmission to enable reductions in vertical, lateral, and longitudinal separation, more direct flights and tracks, and faster altitude clearances.

By 2005, advances in communications, navigation, and air traffic management are expected to save U.S. users in the Oakland Flight Information Region $35 million annually in aircraft direct operating costs and another $45 million in increased payload capability. This represents a savings of 9,000 hours in flight and ground time and 25 million gallons of fuel.

The FAA is currently evaluating and acquiring new technologies, such as, standard terminal automation replacement system, global positioning system, wide area augmentation system, traffic alert and collision avoidance system, digital communications, dependent cooperative surveillance, and decision support systems including final approach spacing, enhanced traffic flow management, conflict probe/resolution, and surface management advisor.

In the long term, additional technologies to improve conflict identification and resolution, data transmission and display, and direct data exchange among aircraft, operation centers, controllers, and pilots are needed. Such improvements are in conceptual development or require investment analyses and funding decisions.

Guiding Principles

Free Flight is an evolutionary concept that is benefits-driven and time-phased. The objective is to provide benefits to airspace users and providers immediately and over time as Free Flight is further developed.

In the near-term, the benefits will focus on actions that increase the users' flexibility to plan and operate aircraft. This will be achieved by concentrating on removing constraints and restrictions to flight planning and scheduling, better exchange of information and collaborative decisionmaking among users and service providers, more efficient management of airspace and airport resources, and tools and models to aid airspace service providers.

The overall guiding principles for moving toward mature Free Flight were developed over a five-month period by RTCA's Task Force 3, which was composed of 250 representatives from the aviation community and the FAA.

The task force published the following list of Free Flight guiding principles:

- Ensure that transitioning to Free Flight will not compromise safety
  The United States operates the safest aviation system in the world. Free Flight is an

innovative concept designed to enhance safety and improve the efficiency of the National Airspace System. Throughout the transition to full Free Flight, safety remains the highest priority.

- Expand the Free Flight definition
  The definition of Free Flight needs to be expanded to include the strategic flight planning and ground phases of operation. During all phases of operation, National Airspace System (NAS) users should have the flexibility to operate in the manner that best suits their operation, subject to system constraints.

- Emphasize initiatives that give users a high return on investment
  System users should be able to recover their investment in a short time period. Initiatives should take advantage of current equipage.

- Transition to Free Flight should be benefits-driven
  Continue to assess anticipated benefits at each stage of exploration and development of Free Flight concepts.

- Emphasize the need for collaborative planning
  In order for system users to realize benefits, there must be a more collaborative decision making process associated with flight and strategic planning. This will entail a greater exchange of real-time information and provide the users with greater flexibility.

- Emphasize procedural improvements with proven technology
  Utilizing existing technology and investments that have already been made, initiate system improvements through procedural changes that require little or no investment in automation (i.e., hardware or software changes). Emphasize changes that use current equipment (e.g., avionics and ATC automation). The FAA should have a significant budget to develop, analyze, and implement new standards and procedures. These funds must include the necessary training costs.

- Consider end-to-end impact and benefits when planning improvements
  The development of improvements and analysis of benefits should be integrated across all phases of operation. For example: improvements en route may result in flights arriving at holding stacks faster or before airport gate availability.

- Address human factors issues during all stages of development
  As system improvements are developed, human factors issues must be included during the analysis and design phases. The significance of necessary training associated with new procedures must be emphasized.

- Assess benefits when possible prior to implementation
  The analysis of benefits is highly complex. At this stage, it is difficult to accurately quantify anticipated benefits. However, it is possible to assign relative measures of qualitative merit. A high level of collaboration with users is required in the formulation of measures and measurement capabilities. After the implementation of initiatives, benefits should be measured.

- Utilize modeling and analysis to anticipate operational impacts on NAS users and service providers
  Continue to develop and utilize appropriate modeling and analysis technologies and utilize to anticipate operational impacts on NAS users and service providers.

- Accommodate users with various levels of equipage during the transition to Free Flight Transition plans should not be dependent upon users equipping their aircraft. Free Flight will accommodate all users, that is, air carrier, air taxi, general aviation, and military. User decisions to equip their aircraft will be benefits-and costs-driven.

APPENDIX B: E-MAIL SURVEY

This Appendix presents the full results of the e-mail survey sent to NAS researchers and stakeholders. First, Figure B.1 illustrates the questions of the survey. Figure B.2 illustrates the numbers of respondents per occupation. Responses appear as received, even if they contain spelling errors or acronyms, there was no editing performed for these responses.

1. What is your primary occupation?
( ) Researcher/ Scientist/ Engineer
( ) Professor
( ) Pilot
( ) Air Traffic Service Provider or Aviation Service Provider
( ) Airline Employee
( ) Aviation Industry Management
( ) Aviation Equipment Manufacturer
( ) Other

2. What do you think are the three most important research issues that must be addressed for Free Flight to be implemented by 2015?
a) Issue 1 -
b) Issue 2 -
c) Issue 3 -

3. Add comments if you wish.

4. Would you like an email response to this survey?
( ) Yes
( ) No

Figure B.1. E-mail survey.

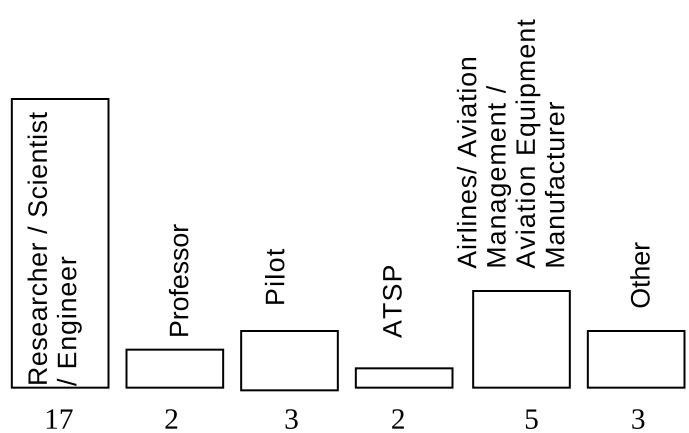

Figure B.2. E-mail survey responses for important Free Flight issues.

Next, all responses to Question 2 are listed. Question 2: *What do you think are the three most important research issues that must be addressed for Free Flight to be implemented by 2015?*

a) Issue 1 - Congestion Management
b) Issue 2 - Airline Prioritization

c) Issue 3 - Increased predictability of the airspace and flight plan

a) Issue 1 - roles and responsibilities of flight crew vs ATC service provider
b) Issue 2 - economic issues including cost-benefit & relationship to mixed equippage
c) Issue 3 - performance issues including HMI and criticality of avionics systems

a) Issue 1 - FAA political and organizational reform
b) Issue 2 - Rigorous operational concept exploration and validation
c) Issue 3 - Preliminary-design trade data generation to support architecture decisions

a) Issue 1 - information collection and coordination
b) Issue 2 - weather data collection and dissemation
c) Issue 3 - pilot/controller/dispatcher roles and responsibilities

a) Issue 1 - congestion/constraint prediction and management
b) Issue 2 - aggregate post event performance evaluation and metrics
c) Issue 3 - methods for equitable access to NAS resources

a) Issue 1 - Safety and Capacity in congested free flight airspace
b) Issue 2 - Transition from today to free Flight
c) Issue 3 - Human Factors - The Free Flying Pilot

a) Issue 1 - Cockpit Resource Management / Sector Resource Management
b) Issue 2 - Integration of DST prototypes (e.g., operational transition, mixed equippage scenarios, feasibility, human performance)
c) Issue 3 - Human factors and automation

a) Issue 1 - ground vs. air nav databases
b) Issue 2 - impact of airborne separation in congested airspace
c) Issue 3 - exchange and presentation of graphics based, rather than nav fixname, profile information.

a) Issue 1 - Traffic Flow Management operational (i.e. procedures) concepts
b) Issue 2 - Traffic Flow management data exchange capabilities & technologies
c) Issue 3 - Traffic Flow Management decision support capabilities.

a) Issue 1 - Communication, Coordination and Visualization of Intent
b) Issue 2 - Collaborative Congestion Management
c) Issue 3 - Dynamic Resectorization

a) Issue 1 - Congestion management and predictability of airspace constraints
b) Issue 2 - NAS-Airline AOC data exchange. Single Point Access to NAS Status."SPANS"
c) Issue 3 - Human Factors with regards to effective collaboration.

a) Issue 1 - development of robust replanning decision aids for air & ground to allow easy selection & monitoring of conflict-free and weather-free routes
b) Issue 2 - air-air & air-ground datalink of intent information
c) Issue 3 - procedure development, failed / degraded operational modes

a) Issue 1 - collaboration
b) Issue 2 - integration of resources
c) Issue 3 - safety

a) Issue 1- Minimize cost to airlines
b) Issue 2- Minimize cost to government
c) Issue 3- Need to break the politics of the FAA who want to preserve the current status quo

a) Issue 1 -Control and responsibility.

b) Issue 2 -Human-computer interface issues; In the end, if we don't develop well designed interfaces, everything fails.
c) Issue 3 -Focusing on what is needed, not what can be done. Let's not add technology or change tasks just because we can.

a) Issue 1 - system integration, including defining a comprehensive ops concept and complete specification of all systems and how they will work together over time
b) Issue 2 - obtaining controller accptance of system changes through appropriate development methods
c) Issue 3 - demonstrated system safety assessments through all stages of the design and development process, not just when field tests or implementation is scheduled to occur

a) Issue 1 - Transfer of intent information from users to service provider both during the planning and execution phases (i.e flight plan filing and data exchange enroute)
b) Issue 2 - Rapid, reliable delivery of constraint information from service provider to users so that both users and the service provide may collaborate on developing solutions to overcome the constraint(s).
c) Issue 3 - Distribution of benefits to participating and non participating users; and quantification of benefits to encourage participation.

a) Issue 1. The roles of the controller and pilot must be made clear in all instances. No matter how technologically advanced, the responsibility/procedures must be worked out.
b) Issue 2. The ability to dynamically realign airspace must be made available to the operational community.
c) Issue 3. Dynamic density must be spelled out and agreed to by the controller workforce.

a) Issue 1 - Define conflict detection and resolution algorithms for airborne and ground systems and define the responsibility for using them.
b) Issue 2 - Extend the CTAS time of arrival spacing to include aircraft on random routes.
c) Issue 3 - Determine the rules for aircraft operating without the minimum"free flight" equipment in a mixed equippage environment.

a) Issue 1 -Clear understanding of roles (pilots, AOC, controller, flow mgt, supervisors, etc.) and attendant workload in whatever FF implementation you're interested in. In particular, how to make sure things don't "fall through the cracks." (e.g. Neither pilots nor controllers notice separation failure because each party has other tasks and assumes some other party is dealing with separation.)
b) Issue 2 -Attention to what a complete system design for a FF NAS is. All the components, not just a few isolated "improvements." Everything you need, how the pieces all fit together, how it will work, and how you'll verify it's working.
c) Issue 3 -Find a way to qualify a point improvement (a new radar with xyz characteristics, say) in terms of how much "better" (need to define that, too)it allows the overall system to work. If we're going to get something going by 2015, we should be making it clear what we are and what we are not going to do and why right now.

a) Issue 1- Agreement on the roles and responsibilities of all the aviation community participants in the new "Free Flight Environment". Results of realistic human-in-the-loop simulations included all players must be bought into by the community.
b) Issue 2 - Uncovering the "real problems with NAS efficiency", most of which have nothing to do with the Free Flight program.
c) Issue 3 - After the "real problems have been identified", put together a research and implementation program that directly tackles the problems.

a) Issue 1 - Human factors studies to see how effective pilots are at using new methods for instrument navigation and how effective pilot are at avoiding conflicts using ADS-B type information ?
b) Issue 2 - Determine what tools are most effective to help pilots in navigation ?
d) Issue 3 - What is the likely increase in capacity if free flight is implemented?

a) Issue 1 - Provide the analysis and demonstrations that clearly establish the requirements for the ground system and the airborne components. To achieve the functional/performance goals of free-flight, the system must be affordability, reliable, and safe. This implies a way to handle system failures and judicate differences between users of the airspace.
b) Issue 2 -
c) Issue 3 -

a) Issue 1- Defining and developing Free Flight such that controllers and pilots know their roles and responsibilities AT ALL TIMES
b) Issue 2- Determining if Free Flight actually provides the benefits being alluded to in all the plans
c) Issue 3- Making Free Flight work in terminal airspace

a) Issue 1 - Determining in what airspace free maneuvering can be beneficial and how to blend and transition such capabilities with high density airspace where ground-based traffic management will continue to be required.
b) Issue 2- Determining how to mechanize distributed air-ground traffic management with integration of the avionics and ATM decision support tools; includes determining roles of pilot and controller, operational procedures, flight deck technology needs, information exchange needs, and reversionary modes in response to system failure; includes making this technology available to general aviation within less dense airspace.
c) Issue 3 - Advancing the flight planning/flight following/revenue optimization processes of the airlines and other airspace users to be in collaboration with the traffic management goals of maintaining safety, order and expeditious flight. Capacity and productivity must be increased while maintaining current levels of safety.

a) Issue 1 - The interrelationships between strategic flow, tactical flow and separation assurance. If strategic flow for the enroute is moving into the 2 hour timeframe, if tactical flow is currently occurring at the 1.5 to 2 hour timeframe, how are these balanced. The controller balances these consideration in his/her brain when conducting separation assurance activities and moving aircraft - the tools don't.
b) Issue 2 - If the tools are not to replace the controller, then they need to be associative to maintain controller skills. If that is the case, what is the point at which automation is not providing additional benefit.
c) Issue 3 - NASA is big on information, why don't they focus on restructuring NAS information to support advanced tools top-down rather than marginal workarounds for tools.

a) Issue 1 - TRANSITION TO FREE FLIGHT IN TIME (now to 2015) AND SPACE (from managed airspace to free flight airspace) => definition and implementation of operational concept in detail, mixed equipped fleet issues, etc.
b) Issue 2 - CONFLICT DETECTION AND RESOLUTION: algorithm, priority, intent information, co-ordination, system implementation, etc.
c) Issue 3 - USE OF FREE FLIGHT EQUIPMENT IN MANAGED AIRSPACE: station keeping, crossing procedure, etc.

a) Issue 1 - Operation of Free Flight within an airspace environment where some users are equipped with modern technology (ADS-B, data-link, etc.) and other users are not equipped. Politically it will probably not be possible to mandate equipage except is high altitude airspace during this time period. Free Flight must also be possible at lower altitudes and in complex terminal airspace.
b) Issue 2 - Controller and pilot acceptance of new ways of doing functions they do today. Many of the automation tools apply automation on top of procedures that are a holdover from days of manual ATC, or inflexible operations based upon ground based NAVAIDS, fixed routes, etc. The fundamental procedures may need to be changed to allow free flight to live up to its promise, and changing procedures that have been in place throughout the careers of ATC personnel will not be a simple task.
c) Issue 3 - Automation tools to help facilitate the separation of aircraft from hazardous weather. Tools that can track weather distrubances, and facilitate routing around these areas, and also ensuring that funneling aircraft into weather clear areas do not create new congestion areas.

Next, additional comments provided in Question 3 are listed.

While traditional research into communications, navigation, surveillance, and air traffic control technologies often generates significant technical improvements, the actual impact on air traffic management operations is often nominal. If NASA research is to make a meaningful contribution to aviation, it must begin to examine the ATM domain where the last remaining unharvested economic benefits (albeit for the users instead of the developers and manufacturers)reside: Traffic Flow Management.

New cockpit technologies will have limited benefits in a non-collaborative environment. Information sharing and ease of access to a multitude of terminal and enroute considerations such as RVR, LLWAS, TDWR, SUA, Field conditions, Local Notams, ITWS, WSP, will make decision making more rapid and accurate. This will offer Airlines a better look at the system as a whole. Airlines operate schedules which make proper decision making critical when adjusting aircraft assignments, crewing, connecting flights, etc. These are major operational needs which need to be fully analyzed equally to
cockpit-ground based navigational technologies which may reduce a flights enroute time by 2-3 minutes.

Need to change the way the FAA works to get this implemented by 2015. Also need to greatly improve coordination between FAA, Mitre, NASA Ames, NASA Langley.

Let's take a top-down review of the NAS across all services, all flow and separation objectives, and identify the major thrust for the future. The approach of this survey smacks of setting a smorgasbord for NASA researchers.

Concepts must be clearly system performance driven and their exploration supported by a suitable analysis toolset. Implementation will happen only if the air traffic service provider is performance driven and has a real interest in improving the system. That's not the current FAA, and perhaps only corporatization or privatization can change that.

Essentially the move towards Free Flight will require significant improvements in the NAS infrastructure, particularly in the CNS arena. The use of information across the NAS will need significant study and improvements since much of the functionality of Free Flight requires wide information collection and coordination. Finally, there is the practical matter of determining a reasonable set of pilot/controller/dispatcher roles and responsibilities under a variety of normal and failure modes.

Issue #3 is closely connected to both Issue #1 and issue #2 since an autonomous separation concept has far different criticality and crew implications compared to a Free Routing concept that may only require avionics upgrades such as enhanced NAV and FMS (and possibly a data-link for trajectory / RTA negotiations).

"Free flight" will never be implemented. It is a goal, not a milestone. Also, once the airspace is congested (in saturation)"free flight" is over. Then it's a variation of "wait in line," or "take a number."

There must also be a consideration (as new automation tools are developed) that the operation and support of complex tools can become cost-prohibitive. Development times are lengthly, and deployment times to multiple sites can take as long as development unless the deployment and support issues associated with complex tools and complex site adaptation are addressed up front in the development time period.

Research is not the primary impediment to the success of free flight. The big issues are political such as what datalink will be used for ADS-B, how will FARs be changed? Development of inexpensive hardware which will enable universal equipage.